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Eelgrass in Buzzards Bay:

Distribution, Production, and Historical Changes in Abundance

BUZZARDS BAY PROJECT

EELGRASS IN BUZZARDS BAY: DISTRIBUTION, PRODUCTION AND HISTORICAL CHANGES IN ABUNDANCE

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BBP-88-05

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ERRATA

for

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Page 114, the last paragraph should read:

> These observations do not rule out the possibility that warm temperatures played a role in the 1931-32 decline, but suggest that temperature cannot be the sole factor in causing regional collapses in eelgrass populations. Instead, other unknown factors must be involved.

Page 26, line 6 should read 107 g C m^{-2} yr^{-1} not 10^{7}.

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FOREWORD

In 1984, Buzzards Bay was one of four estuaries in the country chosen to be part of the National Estuary Program. The Buzzards Bay Project was initiated in 1985 to protect water quality and the health of living resources in the bay by identifying resource management problems, investigating the causes of these problems, and recommending actions that will protect valuable resources from further environmental degradation. This multi-year project, jointly managed by United States Environmental Protection Agency and the Massachusetts Executive Office of Environmental Affairs, utilizes the efforts of local, state, and federal agencies, the academic community and local interest groups in developing a Master Plan that will ensure an acceptable and sustainable level of environmental quality for Buzzards Bay.

The Buzzards Bay Project is focusing on three priority problems: closure of shellfish beds, contamination of fish and shellfish by toxic metals and organic compounds, and high nutrient input and the potential pollutant effects. By early 1990, the Buzzards Bay Project will develop a Comprehensive Conservation and Management Plan to address the Project's overall objectives: to develop recommendations for regional water quality management that are based on sound information, to define the regulatory and management structure necessary to implement the recommendations, and to educate and involve the public in formulating and implementing these recommendations.

The Buzzards Bay Project has funded a variety of tasks that are intended to improve our understanding of the input, fate and effects of contaminants in coastal waters. The Project will identify and evaluate historic information as well as generate new data to fill information gaps. The results of these Project tasks are published in this Technical Series on Buzzards Bay.

This report represents the technical results of an investigation funded by the Buzzards Bay Project. The results and conclusions contained herein are those of the author(s). These conclusions have been reviewed by competent outside reviewers and found to be reasonable and legitimate based on the available data. The Management Committee of the Buzzards Bay Project accepts this report as technically sound and complete. The conclusions do not necessarily represent the recommendations of the Buzzards Bay Project. Final recommendations for resource management actions will be based upon the results of this and other investigations.

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The preparation of this report and the analysis of changes in eelgrass abundance at selected areas of Buzzards Bay was funded by the New England Interstate Water Pollution Control Commission as part of a study of Buzzards Bay by the Environmental Protection Agency. This research, however, has a much longer history involving many individuals and organizations. The initial support from this study came from the Lloyd Center for Environmental Studies and the NOAA National Sea Grant College Program, Dept. of Commerce, Grant No. NA84AA-D-00033, Woods Hole Oceanographic Institution, Proj. No. R/B-68. The volunteers, assistants, and people contributing to this effort are too numerous to mention, but they have my eternal thanks.

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Executive summary

The past and present-day distribution of eelgrass (*Zostera marina* L.) in Buzzards Bay was documented using aerial photographs, field surveys, nautical charts, sediment cores, and first-hand accounts. Today, eelgrass is a dominant habitat along the shallow margins of Buzzards Bay. Eelgrass growth correlates with local temperature and insolation, and annual production is ~350 g C m^{-2} y^{-1}. In Buzzards Bay, eelgrass covers 41 km^2 of substrate and accounts for 11% of primary production; in small shallow bays, eelgrass beds account for 40% of all production. Equally important, these beds act as a nursery, refuge, and feeding ground for many fish, invertebrates, and waterfowl.

A "wasting disease" destroyed virtually all eelgrass in Buzzards Bay (and elsewhere in North America) during 1931-32. All documentation suggests that eelgrass populations equaled or exceeded present-day abundance prior to this catastrophe. Photographs taken 6 to 10 years after the disease show that eelgrass covered less than 10% of the present-day habitat area in Buzzards Bay, and many areas were not recolonized for decades.

The process of recolonization was similar in many areas: new beds initially appeared on bare substrates, beds expanded, additional new beds appeared, and some beds were removed by disturbance. In this way eelgrass population saturated small areas (1-10 ha) 5 to 15 years after initial colonization. Rates of eelgrass colonization over larger regions (100's of ha) depended on distance from refuge populations and heterogeneities of the environment. The greatest rates of eelgrass

expansion occurred during the 1950's and 1960's. Most available substrate was saturated by the 1980's, but eelgrass is still increasing in some areas.

Superimposed on the regional pattern of catastrophic decline and gradual recovery are local changes in eelgrass abundance driven by anthropogenic and natural disturbances. Hurricanes, ice scour, and freezing periodically destroy eelgrass beds in shallow bays or exposed coasts. Eelgrass beds generally recover from these events in 3 to 10 years.

In contrast, more permanent losses of eelgrass habitat have resulted from human perturbation. Considerable amounts of eelgrass habitat areas have been permanently destroyed because of construction or dredging nearshore. Greater and more widespread losses of eelgrass have resulted from water quality decline. For example, eelgrass populations never recovered from the wasting disease or showed new declines in recent years in some poorly flushed, developed bays, with evident or documented declining water quality (New Bedford; Apponaganset Bay, So Dartmouth; Little Bay, Fairhaven; Wareham River; upper Westport Rivers, areas of Sippican Harbor, Marion; and Waquoit Bay on Cape Cod).

In most of these areas, nutrient loading or sediment resuspension from boat activity are implicated as the cause of eelgrass decline. Because the distribution of eelgrass is light limited, eelgrass beds may disappear in enriched areas because increased algal epiphytes and phytoplankton absorb light reaching eelgrass leaves, slowing eelgrass growth or causing death. Sediment resuspension, caused by dredging or power boats, contributes to this pattern of declining light availability

to eelgrass. In clear waters around Buzzards Bay, eelgrass may grow to 6 m MLW or more, but in polluted and disturbed areas, eelgrass grows to 1 m MLW or less, or not at all. Because large portions of eelgrass populations in Buzzards Bay are near the lower limit of eelgrass growth, small changes in water transparency in the future will result in further declines in eelgrass abundance.

In light of these observations and the increasing pressures on the coastal zone, it is recommended that management initiatives to protect eelgrass beds focus on anthropogenic perturbations that result in long term loss of eelgrass habitat. The two areas that deserve the most attention are 1) the restriction of dredging and construction that permanently destroys eelgrass habitat, and 2) the protection of water quality.

Protecting water quality will be difficult because it involves predicting the impact of land based sewage disposal, fertilizer application, and development within watersheds. This is a desirable objective, however, because managing water quality also protects other commercial, aesthetic, and recreational resources within bays. Recent studies suggest that nutrient inputs from residences are impacting many coastal ecosystems, and more stringent regulations are needed for septic setbacks and fertilizer applications nearshore.

In the future, eelgrass populations should be regularly monitored with aerial photograph surveys taken to maximize analysis of eelgrass beds and other submerged features. Sediment cores provide valuable information on long term local changes in eelgrass abundance because the remains of eelgrass seeds (as well as other plant and animal remains)

are preserved in mud for hundreds of years. Future research on the long-term impact of anthropogenic disturbance and changes in coastal communities should utilize this largely unexplored data base.

Overview

Introduction

Eelgrass (*Zostera marina* L.) is a subtidal marine angiosperm common in temperate waters in the Northern Hemisphere. It is one of more than 60 species of seagrasses that grow in the worlds oceans. In Buzzards Bay and Cape Cod, eelgrass beds are abundant, often forming extensive underwater meadows. The areal cover of eelgrass habitat is twice that of salt marshes in this region, but because these beds are subtidal, they are unnoticed, except by boaters, shellfisherman and divers.

Eelgrass beds are often inconspicuous from the surface, but they are productive and valuable resources. Eelgrass beds are ecologically important in coastal waters because they serve as nurseries, refuge, and feeding grounds for fish, waterfowl and invertebrates. Eelgrass meadows also bind, stabilize, and change the chemistry of sediments.

In Chapter 1, I describe in detail the present day distribution of eelgrass in Buzzards Bay, and in Chapter 2, I estimate the contribution of eelgrass growth to productivity in Buzzards Bay.+

The wasting disease of 1931-32 destroyed virtually all eelgrass in this area, and most areas did not recover for many decades. In Chapter 3, I document this and other declines due to disease by analyzing eelgrass seed deposition in sediment cores. I also reanalyze the causes of the disease and the slow recolonization process in Chapter 4.

Superimposed on the collapse of eelgrass populations during this century are local patterns of decline and recolonization driven by both natural and anthropogenic disturbances, including storms, ice scour and freezing, and pollution. In Chapter 4, I also document 12 "case histories" of changing eelgrass abundance that involve these processes.

Because eelgrass beds are ecologically important, and are increasingly affected by anthropogenic perturbations, there is interest in resource management initiatives to protect these communities. In addition, the widespread distribution of eelgrass and its sensitivity to pollution make it a potential indicator species for changes in water quality. I address both these management concerns in Chapter 5.

There are some excellent reviews of eelgrass biology and ecology available (e.g. Thayer et al., 1984) and certain topics are covered in detail elsewhere in this report, therefore I will outline only the more salient features of eelgrass biology below.

General biology and ecology of eelgrass.

Eelgrass is a vascular plant composed of 3-7 strap-like leaves, bound together in a sheath attached to an underground rhizome (Fig. 1). In this region, the leaves are less than 1 cm wide, and range 20 - 160 cm long. The leaves are adapted to the marine environment in several ways. The leaf cuticle is thin and multiperforate and allows the uptake of nitrogen, phosphorus, and inorganic carbon through the leaf surface (McRoy and Barsdate, 1970; Penhale and Thayer, 1980; Thursby and Harlin, 1982). Air compartments (lacunae) extend throughout the leaves and keep them buoyed in the water. Most chloroplasts are located in epidermal

cells of eelgrass, for efficient light absorption (Tomlinson, 1980; Dennison and Alberte, 1982).

A basal meristem, enclosed within the leaf sheath, produces new leaves, rhizome segments, and lateral shoots. Clusters of roots on each rhizome node, penetrate the sediment 30 cm or more. The roots function both in anchoring the plant and are the primary site of N and P uptake (Penhale and Thayer, 1980). As eelgrass grows, the base of the shoot pushes through the sediment.

Eelgrass is found in diverse habitats in temperate waters. Locally, the upper limit of growth is set by physical factors such as wave action, ice scour, and desiccation. The lower limit of eelgrass growth is set by the period of light intensity above photosynthetic saturation and compensation (Dennison and Alberte, 1985, 1986; Dennison, 1987). Thus in turbid bays without appreciable wave energy, eelgrass ranges from low intertidal to 2.0 m MLW or less; in wave-swept coasts with clear water, eelgrass begins at 1-2 m MLW and may grow as deep as 12-45 m (Sand-Jensen and Borum, 1983; Lee and Olsen, 1985, Cottam and Munroe, 1954). Mean secchi disk depth is a good predictor of maximum depth of eelgrass growth (Dennison, 1987).

All stages of the eelgrass life cycle occur underwater, including flowering, pollination, and seed germination (Ackerman, 1983; den Hartog, 1977, Taylor, 1957a+b). There is latitudinal variation in phenology, and in New England, peak flowering occurs in April and May (Silberhorn et al., 1983), but there is often variation among habitats.

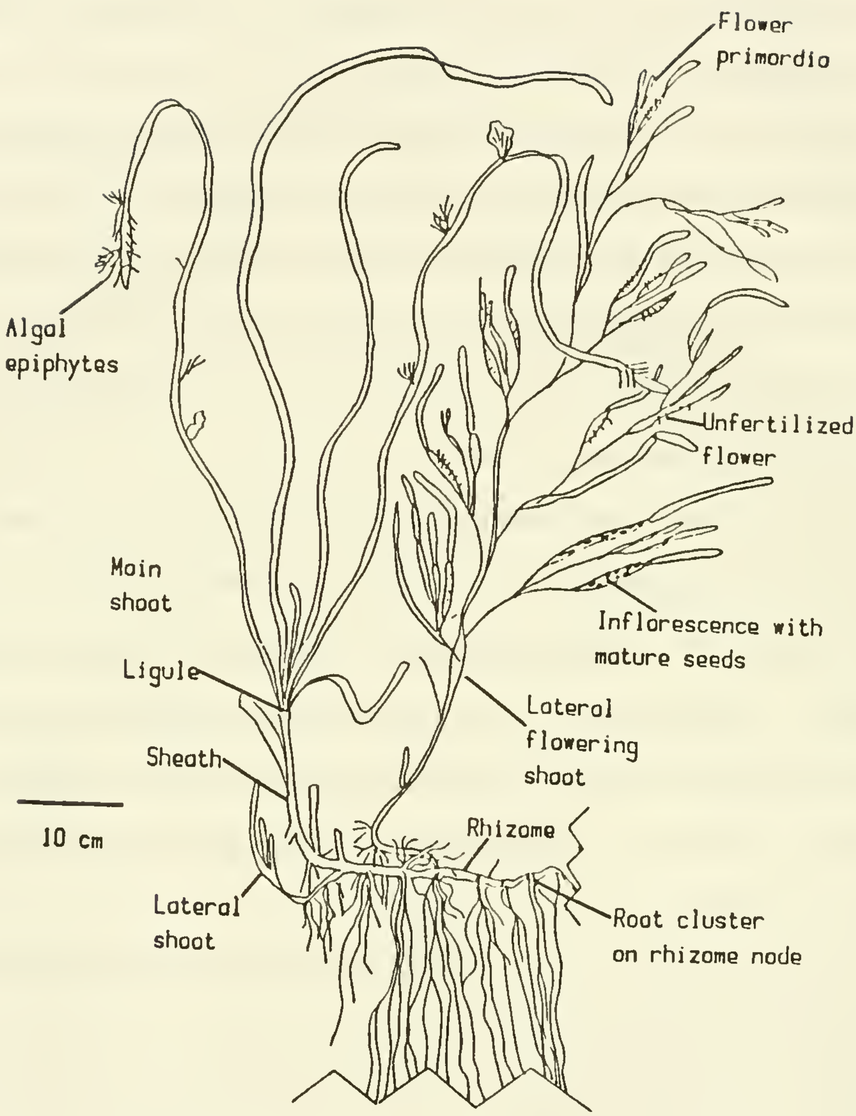

Figure 1. General morphology of *Zostera marina*.

Eelgrass leaves are bound together in a sheath attached to an underground rhizome with clusters of roots on each rhizome node. Lateral vegetative or reproductive shoots may originate from within the sheath of the main shoot. The inflorescence on the lateral reproductive shoot contains both male and female flowers. Reproductive shoots may also originate from new seedlings or the main vegetative shoot may develop into a flowering shoot.

Eelgrass is a perennial, and grows during winter, but plants in shallow water (<1 m MLW) are functional annuals because they are killed by ice scouring, freezing, or other stresses (Phillips et al. 1983; Robertson and Mann, 1984). Plants exposed to these conditions typically have a high incidence of flowering. There have been reports of genetically determined annual populations (Keddy and Patriquin, 1978; Keddy, 1987), but evidence for this hypothesis is not conclusive (Gagnon et al., 1980; Phillips et al., 1983).

Eelgrass grows in diverse habitats ranging from anoxic muds in poorly flushed areas to sand and gravel bottoms with current velocities up to 1.2-1.5 m s^{-1} (2.3-2.9 kt; Fonseca et. al. 1982a, 1983; Pregnall et al., 1984). The morphology of eelgrass shows considerable plasticity in growth in response to physical energy of the environment and nutrient content of sediments (Kenworthy and Fonseca, 1977; Phillips et al, 1983; Short, 1983; Thayer et al., 1984). For example, plants growing in shallow, wave-swept bottoms tend to have short narrow leaves, grow in high densities (>1000 shoots m^{-2}), and produce dense root and rhizome clusters; whereas plants growing in deeper water have longer broader leaves, grow in lower densities (<200 m^{-2}), and produce less root and rhizome material.

Eelgrass beds are maintained and expand by vegetative lateral shoots and by recruitment of new seedlings. Because most shoots in a bed may be derived from vegetative growth of a few plants, it is often stated that eelgrass beds are large clonal populations. Bare areas not adjacent to existing eelgrass beds are colonized almost completely by

new seedlings because uprooted plants float and tend to be cast ashore or washed out to sea.

Eelgrass aboveground production typically ranges 200-500 g C m^{-2} y^{-1} (Jacobs, 1979; Kentula and McIntire, 1986; Robertson and Mann, 1984; Thayer et. al, 1984; McRoy and McMillan, 1977) and may locally exceed production by phytoplankton and macroalgae in shallow bays (Sand-Jensen and Borum, 1983). Epiphytic algae often contribute sizably to the productivity of these communities (Penhale, 1977; Penhale and Smith, 1977; Mazella and Alberte, 1986). Most eelgrass production enters a detritus based food web (Harrison and Mann, 1975; Kenworthy and Thayer, 1984; Mann, 1972; Thayer et al., 1975), but direct consumption by herbivores such as waterfowl and isopod crustaceans may be locally significant (Nienhuis and Van Ireland, 1978; Nienhuis and Groenendijk, 1986).

Carbon fixation is just one role of eelgrass beds in coastal waters. Eelgrass meadows act as a nursery, feeding ground, and refuge for numerous animals (Adams, 1976; Heck and Orth, 1980a+b; Kickuchi, 1980; Lewis, 1931; Thayer and Stuart, 1974; Thayer et al., 1984;). When eelgrass colonizes an area, it changes the physical, chemical, and biotic properties of sediments (Kenworthy et al., 1982; Marshall and Lukas, 1970). As eelgrass biomass increases, so does organic matter, fine sediment fractions, and infaunal invertebrate diversity (Orth, 1973, 1977).

Eelgrass beds, like other seagrasses, bind, baffle, and stabilize sediments and may also influence coastal erosion (Burrell and Schubel, 1977; Churchill et al., 1978; Fonseca et al., 1982a, 1983; Fonseca and

Kenworthy, 1987; Schubel, 1973). Eelgrass leaves reduce shear stress of water motion on sediments because current velocity at the top of an eelgrass canopy may exceed 1 m s^{-1}, whereas velocity at the base of the shoots is nil (Thayer et al., 1984; Fonseca et al., 1982a). When the wasting disease destroyed eelgrass beds in the 1930's, the physical characteristics of adjacent beaches often changed appreciably (Rasmussen, 1977).

Anthropogenic and natural disturbances play a significant role in regulating the abundance and distribution of eelgrass and other seagrasses. Certainly the most profound natural disturbance affecting eelgrass abundance during this century was the wasting disease of 1931-33 that eliminated at least 90% of the eelgrass in the North Atlantic, including Massachusetts (Cottam, 1933, 1934; den Hartog, 1987; Rasmussen, 1977). Many areas were not recolonized for decades, and in some locales, eelgrass is still expanding today (den Hartog, 1987). There is evidence that eelgrass populations periodically collapse (Cottam, 1934), and recent outbreaks of the wasting disease have been reported (Short et al., 1986). Other natural disturbances remove eelgrass including catastrophic storms, periodic storms, sediment transport, ice damage, and biological removal (Harlin et al., 1982; Jacobs et al., 1981; Nienhuis and van Ireland, 1978; Orth, 1975; Robertson and Mann, 1984).

Anthropogenic disturbances include physical removal, toxic pollution, and degradation of water quality (Borum, 1985; Cambridge, 1979; Cambridge and McComb, 1984; Fonseca et al., 1985; Kemp et. al., 1983; Larkum and West, 1982; Nienhuis, 1983; Orth and Moore, 1983b;

Thayer, et al., 1975). While any of these human perturbations may be locally important, declining water quality has often resulted in the largest areal losses of eelgrass and other seagrasses (Cambridge, 1979; Cambridge and McComb, 1984; Lee and Olsen, 1985; Orth and Moore, 1983b; Nienhuis, 1983).

Chapter 1

The distribution of eelgrass (*Zostera marina* L.) in Buzzards Bay

Introduction

Coastal regulators and biologists need accurate inventories of seagrass distribution to understand the biological role of these communities and to manage them. In Buzzards Bay, eelgrass (*Zostera marina* L.) is a major component of shallow waters, and an important habitat and nursery for many species, but knowledge of eelgrass distribution has been lacking. This report is intended to fill this void.

Elsewhere, seagrass distribution has been mapped over large geographic areas using aerial photographs together with field verification (Orth and Moore, 1983a). Under favorable conditions, such as good water clarity, low winds, and low tides, eelgrass beds can be seen easily on vertical aerial photographs. As with any remote sensing methods, photographs must be interpreted carefully; for example, annual beds in very shallow waters may be absent between December and early March. Nonetheless, photographs can provide a reliable and accurate record of eelgrass abundance, especially when several recent surveys are available for comparison.

Methods

Eelgrass was mapped in Buzzards Bay using vertical aerial photographs and field validation. The region was subdivided into 12 subareas (Fig. 1), each of which are mapped and described in detail

(Appendix II). The Elizabeth Islands were not mapped, but eelgrass abundance there was estimated from substrate area on maps (Appendix II).

Photograph interpretation

The maps of the present-day distribution of eelgrass were based on existing black and white or color vertical aerial photographs taken by private and governmental agencies (Appendix I). Most of the photographs used were taken between Spring and Fall, during 1974 - 1981. Maps of eelgrass based on photographs taken during the 1970's are often representative of present-day eelgrass distribution because eelgrass had saturated available habitat in most areas by that time (refer to chapter 4). Because older photographs may lead to underestimates of new eelgrass losses or other recent changes, the dates of aerial surveys used to make each map are listed in Appendix II.

Field verification of photographs was accomplished either by skin- or SCUBA diving, or surface observations from boats in 1984-1986. In some embayments, interpretation of photographs was aided by information from shellfish wardens, other researchers, or local residents.

Older photographs and winter surveys were used to interpret recent photographs. For example, a submerged feature unchanging in area over several decades is either a rock field or peat reef, whereas a patch of dense vegetation that shows gradual expansion is eelgrass because only eelgrass beds change in this way. Submerged features in basins that show radical movement within one or two growing seasons are probably drift material. Vegetation present only on summer imagery is likely to be an annual eelgrass bed.

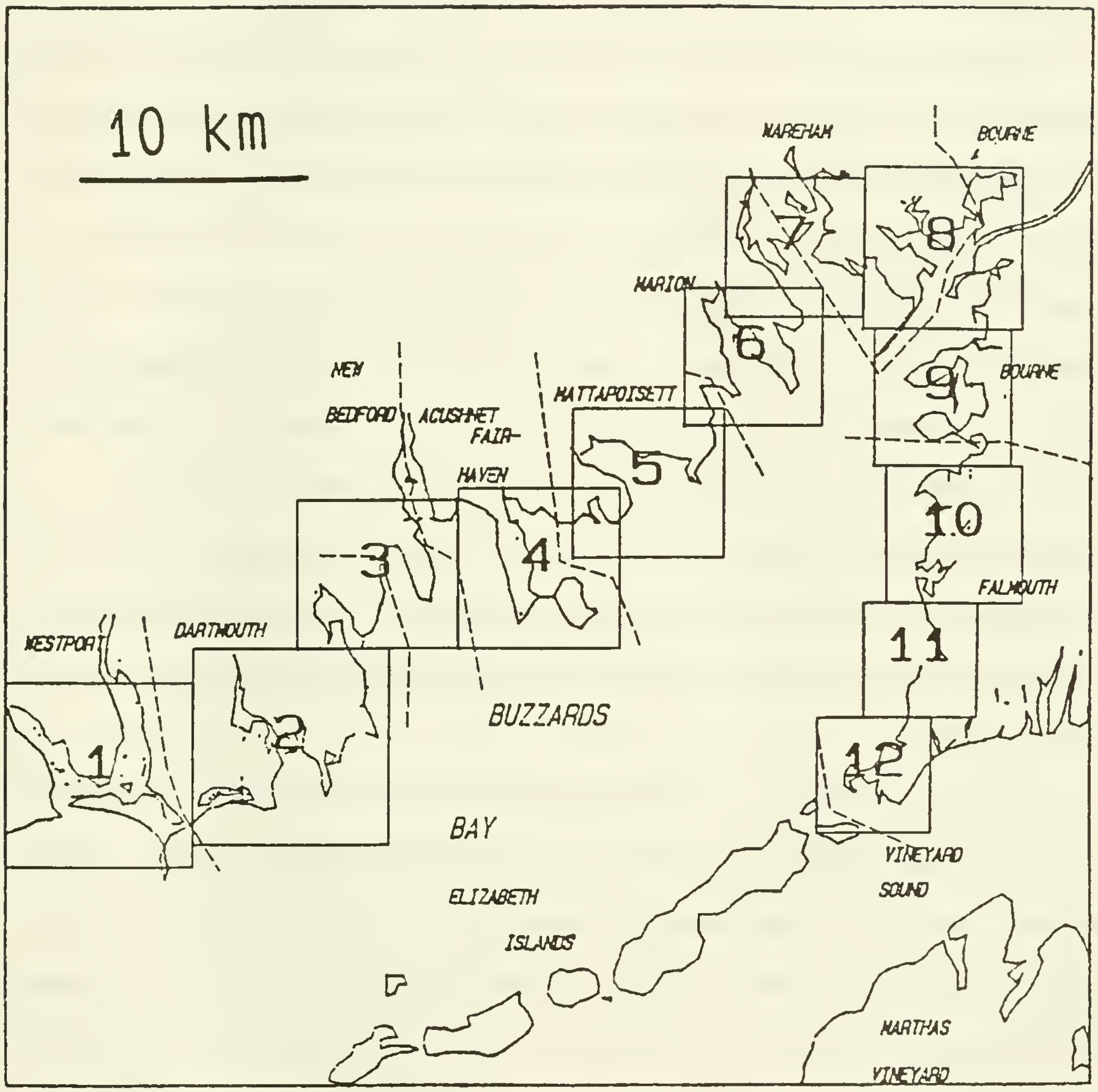

Figure 1. Map of Southeastern Massachusetts.

The location of the 12 subareas individually mapped and described in Appendix II.

The lower boundaries of eelgrass beds could not be identified in some instances on any photographs and were estimated from bathymetry and typical depth of eelgrass growth for that area. These beds are listed in the results.

Eelgrass beds are rarely continuous patches of vegetation; instead there are bare areas within these beds of varying size. Some of these bare areas are apparent on photographs to the unaided eye, some become apparent when a photograph image is magnified, others are below the limit of resolution of a photograph and can only be measured in the field or on small scale aerial surveys. Alternatively, eelgrass may occur as numerous discrete patches too small and numerous to digitize. In all these cases, a perimeter was drawn around eelgrass beds or clusters of eelgrass beds on photographs, and the percent cover of this outlined "bed" --as viewed on a photograph with the unaided eye-- was estimated using a percent cover scale chart (Fig. 2, c.f. Orth and Moore, 1983a).

The accuracy of visually estimating percent cover was tested by placing a photograph under a dissecting scope with cross-hairs, and randomly moving the photograph between 50 and 100 times. The actual percent cover was calculated by dividing the number of times the cross-hair landed on eelgrass by the total number of observations. In general, visual estimates of large scale percent cover were accurate within 15% of this random count method.

Mapping techniques

To map eelgrass beds, aerial prints were overlaid with a sheet of acetate, eelgrass beds were outlined, and other notes were recorded. The photographs and overlays were subsequently photographed with B&W slide film, and this image was projected onto a map of 1:25,000 scale or smaller. The eelgrass beds were then redrawn by hand and distortions in the image were compensated for by eye or manipulating the image on a film enlarger. These bed outlines were re-traced using a digitizing pad connected to a microcomputer. Digitizing and mapping programs for a microcomputer were used for data storage, area analysis, and plotting at different scales.

The maps produced here have ~25 m resolution. The process of projection, tracing, and digitizing, however, introduced random errors in bed position. These errors were small, and the position of eelgrass beds on the maps in this report were generally accurate within 40 m for beds adjacent to the shore, 60 m for beds within 0.5 km of shore, and within 80 m for eelgrass beds more than 0.5 km from any shoreline when compared to bed positions measured directly from the source photographs.

Each subarea is shown with political boundaries and site names and again with eelgrass beds drawn. In the latter, eelgrass beds are drawn with dashed lines and coastlines as solid lines. Bed areas were computed from the stored coordinates and reported as hectares [1 ha = 2.47 acres].

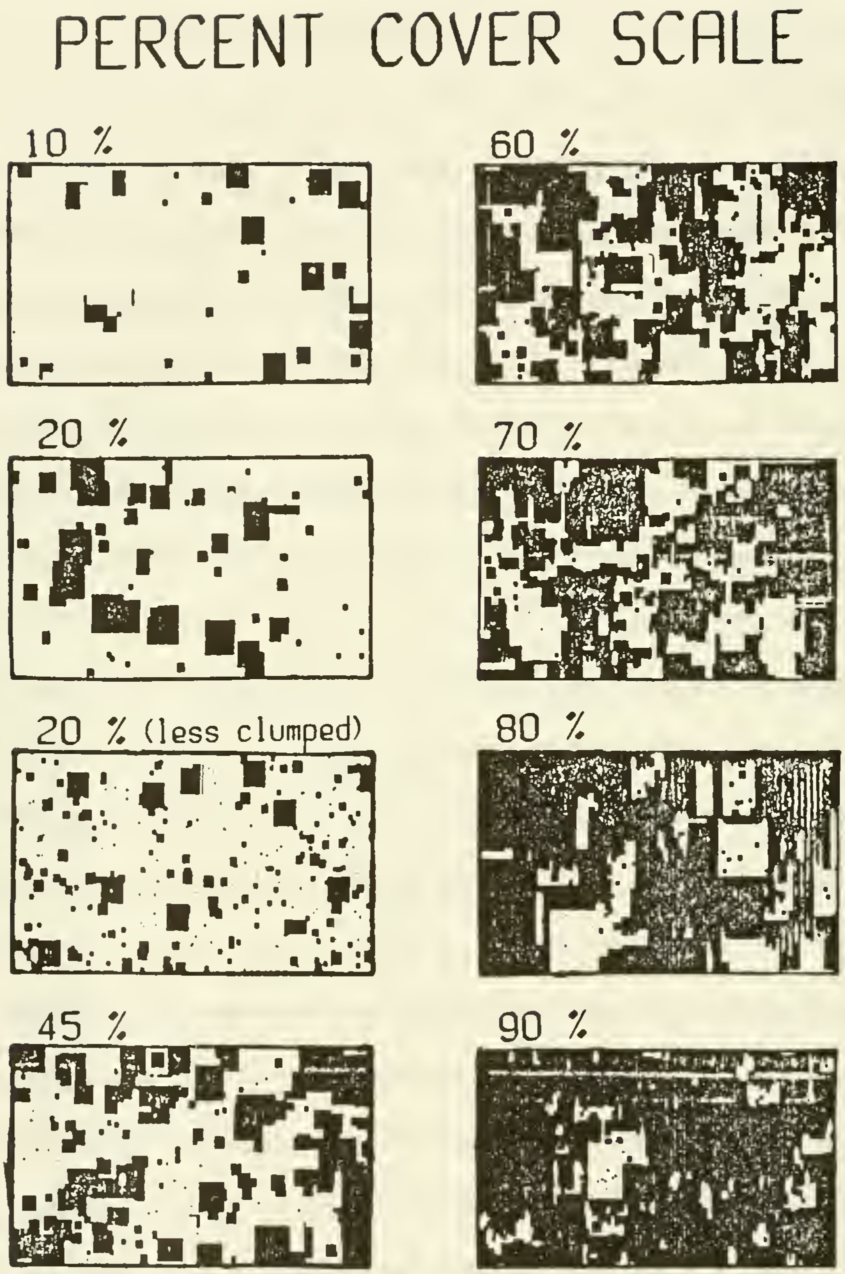

Figure 2. Percent cover scale.

This scale was used to visually estimate eelgrass cover of eelgrass beds outlined on photographs. The two 20% cover boxes showing different degree of clumping illustrate how patchiness may vary with the same degree of cover.

Not all areas were mapped because of inadequate aerial coverage. Areas where eelgrass is present, but its exact boundaries are unclear, are labeled "+". Areas where eelgrass is present, but has a patchy distribution covering less than 5% of the bottom over large areas, are labeled "SP". Areas where vegetation is present, but its identity is unclear, are labeled "?". These and other symbols used on the maps are summarized in Table 1. All maps are oriented with true north at the top.

Results

General features

The central portion of Buzzards Bay is too deep for eelgrass growth, however eelgrass meadows typically dominate shallow areas (refer to Appendix II for a detailed description of eelgrass in the Bay). On high energy coasts and well flushed areas, eelgrass typically grows on sand or sandy-mud to 3-6 m MLW; in protected embayments, eelgrass most often grows on mud bottoms to 1-2 m. In fact, eelgrass beds are a dominant feature in nearly all shallow areas in the region--often forming a continuous belt of vegetation for thousands of meters--except around New Bedford, and the heads of certain bays and estuaries (e.g. Apponagansett Bay, East Branch of the Westport River, the upper Wareham River, and coastal ponds in Falmouth).

Several features are apparent on aerial photographs that deserve discussion because they affect estimates of eelgrass cover. On the outer coast, eelgrass beds appear as dark patches on a light background (sand). In some exposed areas, algae covered rock and cobble dominate

Table 1. Key to the symbols used on the maps.

On all maps in this report, the north-south meridian is parallel to the sides of the maps, and true north is at the top.

	Coastline (solid line)
	Eelgrass bed (dashed lines or darkened area)
+	Eelgrass present, bed dimensions unclear
±	Eelgrass distribution variable on recent photographs
?	Submerged vegetation, possibly eelgrass
PA	Patches of eelgrass present
NA	Photograph coverage not available for area
NI	Area not included in survey
AA	Attached algae, usually on rock or cobble
DA	Drift algae may be present on some photographs
B	Location of shoot counts or biomass harvesting
PE	Salt marsh peat reef offshore

BOPH5 Eelgrass bed ID #. The first two letters indicate town, the second two indicate local, then the number of the bed. In this case bed 5 in Phinneys Harbor in the town of Bourne. The town letters are omitted on the maps, but are included in Appendix III.

Several features are apparent on aerial photographs that deserve discussion because they affect estimates of eelgrass cover. On the outer coast, eelgrass beds appear as dark patches on a light background (sand). In some exposed areas, algae covered rock and cobble dominate the bottom, as well. Algal diversity is high in this region, but *Fucus* and *Ascophyllum* are most common in the intertidal, and *Chondrus*, *Ceramium*, *Codium* and *Sargassum* in the subtidal. In addition, kelps are abundant in some deep, rocky areas with clear water, such as around the Elizabeth Islands and off Westport and Dartmouth. Most of these algae-covered rock and cobble fields can be distinguished from eelgrass beds by their characteristic "texture".

In protected areas with mud bottoms, contrast between eelgrass and its background is reduced, but eelgrass can usually be discerned as a dark patch on a slightly lighter bottom. In some bays, benthic drift algae form large mats which can be mistaken for eelgrass beds, but eelgrass growing in these areas appear as a slightly lighter patches on a dark background.

In moderate energy environments, with shell and gravel bottoms, the green alga *Codium* may be abundant within eelgrass beds. *Codium* can also dominate the bottom below depths of eelgrass growth, making it difficult to estimate eelgrass bed dimensions and percent cover of eelgrass in some areas. Even though *Codium* is common, it rarely covers the bottom in as large an area, or as densely as eelgrass beds.

Salt marsh peat reefs, remnants of salt marshes covered by migrating barrier beaches then re-exposed after sea-level rises, are common in some areas, usually near existing marshes. These reefs have a

similar appearance to eelgrass beds, but usually can be identified on photographs, because, unlike eelgrass beds, they frequently appear in the surf zone.

Questionable areas that were not field validated are identified in Appendix II.

Region wide summary

Eelgrass coverage was broken down by town, including the estimate for the Elizabeth Islands (Table 2). On the mainland portion of the bay, there are 3600 hectares of eelgrass habitat. An additional 540 ha were added for production measurements as to account for eelgrass along the Elizabeth Islands (Appendix II). When these bed areas are corrected for percent cover, they amount to a total of 2670 ha of eelgrass bed cover in Buzzards Bay.

Several comparisons can be made between eelgrass habitat area and other substrate types. For example, in Buzzards Bay, eelgrass beds cover twice the area salt marshes (Table 3). To a large degree, the amount of eelgrass within a towns boundary depends on the area of suitable substrate. Bathymetric contours are drawn on nautical charts at 1.8, 3.6, and 5.4 m (6, 12, and 18 ft). Most (but not all), eelgrass grows in less than 3.6 m of water in Buzzards Bay, therefor this is the most meaningful reference contour.

The ratio of eelgrass habitat area to substrate area less than 3.6 m varies markedly in each town (Table 3), and this pattern of distribution can be explained by differences in hydrography, water quality, and disturbance levels in each part of the Bay. Three towns

(New Bedford, Dartmouth, Westport) have substrate-eelgrass area ratios higher than other towns in Buzzards Bay which range 1.5-2.5. These higher ratios (e.g. 350 for New Bedford) can be explained in part by the loss of eelgrass bed area that I report in Chapter 4. If the substrate-eelgrass habitat area throughout Buzzards Bay equaled the mean ratio for the less polluted towns (2.1), then there would be 15% more eelgrass along the mainland portion of Buzzards Bay. This suggests that chronic pollution in Buzzards Bay has already eliminated 15% of potential eelgrass habitat.

Discussion

In Buzzards Bay today there are ca. 4500 hectares of benthic habitat where eelgrass is a conspicuous biological component. When corrections are made for percent cover of this habitat as apparent on aerial photographs, as well as adjustments for unmapped area, there are approximately 2900 hectares of eelgrass bed cover.

In one sense, this is an underestimate, because this total does not take into account the eelgrass indicated with a "+" on the maps or other questionable areas. On the other hand, the eelgrass bed dimensions reported here were largely based on photographs between 1974 and 1981, and documentation in Chapter 4 suggests that eelgrass cover has declined in some areas and expanded in others in recent years. Nonetheless, given these errors and omissions, as well as including mistakenly identified submerged vegetation, this estimate of total eelgrass cover for Buzzards Bay is probably accurate within 300 hectares.

Table 2. Eelgrass cover by town around Buzzards Bay.

All areas in ha, including eelgrass habitat area, area corrected for percent cover, and additional estimated area in unmapped regions, including the Elizabeth Islands.

Town	Total habitat area	Eelgrass beds (adj % cov.)	Additional bed area (est.)	Total (adj % cov.)
Bourne	656	447	30	477
Dartmouth	>107	74	30	104
Fairhaven	450	346	-	346
Falmouth (Bay shore)	559	397	-	397
Marion	331	189	-	189
Mattapoisett	446	317	-	317
New Bedford	0.7	0.2	-	0.2
Wareham	918	564	-	564
Westport	>180	125	140	265
Elizabeth Islands (est)	540	270	-	270
TOTALS:	4188	2729	200	2929

Table 3. Eelgrass habitat area in Buzzards Bay compared to salt marsh area, and substrate less than 3.6 m MLW.

Eelgrass habitat areas in Dartmouth, Westport, and Bourne were adjusted for missing coverage. Salt marsh areas from (Hankin et al., 1985). The Elizabeth Islands are not included in totals. The mean substrate-eelgrass habitat area ratio was 2.1 (excluding New Bedford, Dartmouth, and Westport).

Town	**Eelgrass habitat area**	**Substrate < 3.6 m area**	**Substrate -eelgrass ratio**	**Salt marsh area**
Bourne	700	1130	1.6	121
Dartmouth	151	823	5.5	463
Fairhaven	450	1190	2.6	246
Falmouth (Bay side)	559	1397	2.5	106
Marion	331	870	2.6	124
Mattapoisett	446	630	1.4	142
New Bedford	0.7	240	343	0
Wareham	914	1480	1.6	364
Westport	389	1420	3.7	427
TOTALS:	3940	9180		1993

For mapping and data management purposes, this eelgrass coverage was subdivided approximately 400 "beds" as listed in Appendix III. Because eelgrass may grow continuously along several kilometers of shore with different levels of density, and sometimes span several photographs, the borders of the beds that I have drawn often reflect the scale of the imagery, extent of photograph coverage, and idiosyncrasies of the mapping process. Thus, it is not meaningful to say that town A has more eelgrass beds than town B; instead it is more appropriate to discuss the total eelgrass bed area in each town.

Less than one third of the eelgrass in Buzzards Bay occurs in shallow, protected bays and estuaries with restricted water flows; the remainder occurs in higher energy, better flushed offshore waters. Because water transparency is not good in shallow, poorly flushed embayments, particularly where there is considerable human development, eelgrass grows only to 0.6 - 1.8 m. In cleaner, offshore, well flushed waters, eelgrass grows to 3.0 to greater than 6.0 m (Fig. 3). This distinction is relevant because each of these areas are host to different communities of animals.

In shallow, quiescent lagoons, eelgrass grows as high as the low water mark, and annual plants may even occur on intertidal flats. Plants in shallow areas are available to, and important food sources for waterfowl, particularly Canada geese. These beds are also important habitats and nursery grounds for estuarine fish and invertebrates. In contrast, eelgrass growing along exposed beaches may begin 1.0 m MLW or deeper because of wave action, and leaves are generally not available to

waterfowl. Furthermore, while there is considerable overlap of invertebrate species, larger fish such as striped bass, bluefish, tautog, flounder, and cownosed rays forage much more frequently in offshore eelgrass beds than beds in shallow embayments. Thus, the ecological consequences of loss of eelgrass habitat will greatly depend on the location of the bed.

The depth that eelgrass grows depends on light availability. Light availability is largely controlled by phytoplankton abundance and algal epiphyte cover (mostly determined by nutrient loading and flushing) and sediment resuspension (Dennison, 1987; Kemp et al., 1983; Lee and Olsen, 1985; Orth and Moore, 1983b; Sand-Jensen and Borum, 1983). Figure 3 shows that light is less available to eelgrass in poorly flushed embayments than on more exposed shorelines, and water transparency is best near the southern and eastern shores of Buzzards Bay, than the northwestern end which is not as well flushed, and has moderate riverine and larger anthropogenic inputs.

The absence of eelgrass in the north ends of embayments such as New Bedford Harbor, Little Bay, Fairhaven, and Apponagansett Bay, Dartmouth does not correspond to physiological limits of eelgrass growth due to the low salinities or damage due to natural disturbances. Because eelgrass grew in these areas in the past (Chapter 4), alternate explanations must account for the absence of eelgrass, such as toxic pollution, sediment resuspension, or nutrient enrichment.

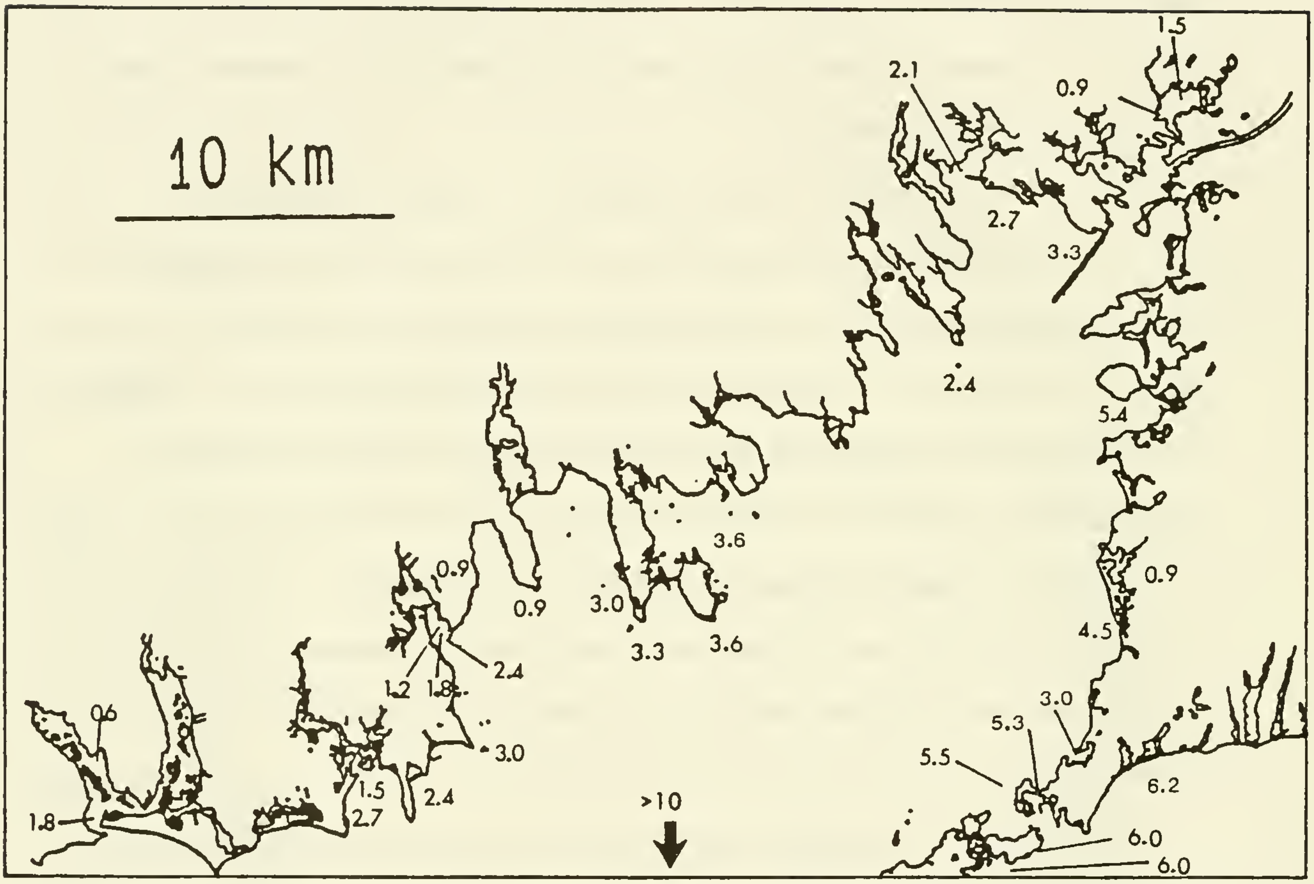

Figure 3. Maximum depth (m MLW) of eelgrass in different parts of Buzzards Bay.

In general, water transparency is greater in the southern region of the Bay than northern parts, and better outside of small embayments than within.

Chapter 2

Eelgrass (*Zostera marina* L.) production in Buzzards Bay

Introduction

The contribution of *Zostera marina* L. (eelgrass) to primary production in Buzzards Bay has not been estimated. Elsewhere, *Zostera* beds contribute sizably to coastal primary production, especially in shallow embayments, where they may account for 50% of all primary production including benthic algae and phytoplankton (Sand-Jensen and Borum, 1983; Nienhuis and Van Ireland, 1978).

In Chapter 1, I showed that there are 2930 ha of eelgrass bed cover in Buzzards Bay. This estimate was calculated from photographs of ≈1:25,000 scale photographs, and adjusted for percent cover as perceived on that scale imagery. This process ignores bare patches within eelgrass beds that are too small to be seen on those photographs, and which are only visible underwater or with small scale imagery. It is impossible to quantify small scale patchiness in every bed in this region, so this bed cover area was multiplied by a correction factor (0.8) based on field experience and microscopic study of photographs (Costa, 1988). Therefore, the "production area" of eelgrass in Buzzards Bay is 2482 ha

In southeastern Massachusetts, annual above- and belowground eelgrass production is approximately 393 g C m^{-2}, and aboveground production alone is 350 g C m^{-2} (Costa, 1988). Hence, the 2500 ha

(production area) of eelgrass in Buzzards Bay fix (above and belowground) 0.9×10^{10} g C each year.

Comparison of eelgrass and other primary producers in Buzzards Bay

Phytoplankton

Carbon fixation in Buzzards Bay is approximately 10^{7} g C m^{-2} y^{-1} (Roman and Tenore, 1978). Because the area of Buzzards Bay and its adjoining bays and estuaries is 5.5×10^{8} m^{-2} (Signell, 1987), phytoplankton annual production in Buzzards Bay is $\approx 5.9 \times 10^{10}$ g C.

Macroalgae

Many macroalgae grow deeper than eelgrass, and drift algae often accumulate on the bottoms of quiescent bays. Nonetheless, macroalgal cover, like eelgrass, is not appreciable in Buzzards Bay because most of the Bay is greater than 10 m deep, and light penetration is insufficient at that depth to support a large biomass of benthic algae. Furthermore, in the open bay, most algae are restricted to solid substrate, and rocky areas are only extensive around the Elizabeth Islands, offshore of Westport and Dartmouth, and in shallow areas, especially within 100 m of shore. The vast majority of the shallow margins of the Bay bottom is mud and sand, and is suitable only for eelgrass colonization. Based on aerial photographs, it appears that algae cover less than 10% of the habitat area of eelgrass, or about 400 ha.

Production estimates for attached algae in temperate waters are quite variable and generally range from 100 - 1000 g C m^{-2} y^{-1} (Ferguson et al., 1980; Josselyn and Mathieson, 1978; Mann, 1972; Wassman and

Rasmuss, 1973). Estimates of drift algae production are infrequent. Thorne-Miller et al (1983) found summer biomass of unattached benthic algae in Rhode Island Coastal lagoons to be 14 - 125 g dry m^2 but did not estimate annual production. Sand-Jensen and Borum (1983) estimated macroalgal production in coastal waters with eelgrass beds 200-500 g C m^{-2} y^{-1}. In this paper, 500 g C m^{-2} y^{-1} was conservatively estimated for both drift and attached macroalgae, where they are dense. Thus macroalgal production in Buzzards Bay is ≈ 20 x 10^8.

Epiphytic algae

Numerous species of algae are epiphytic on eelgrass (Harlin, 1980), and production estimates range from 1 to 100% of eelgrass production, although 20 - 40% are most frequently reported (Borum and Wium-Anderson, 1980; Mazella and Alberte, 1986, Penhale, 1977; Sand-Jensen and Borum, 1983). In Buzzards Bay, dense accumulations of epiphytic algae are usually found in poorly flushed areas, especially near sources of nutrient inputs. Offshore eelgrass beds typically have much lower accumulations of algal epiphytes, and because these beds make up approximately 70% of eelgrass cover in Buzzards Bay, total overall epiphytic algal production was conservatively estimated to be 20% of eelgrass production.

Periphyton

Periphyton production on the surface of sediments and solid surfaces range from 4 to 200 g C m^{-2} y^{-1} and are most abundant on muddy sediments in shallow waters without macrophytes, and are less productive

in sand (Hickman and Round, 1970; Marshall et. al., 1971; Ferguson, et al., 1980, Revsbeck et al., 1981; Sand-Jensen and Borum, 1983). Sand-Jensen and Borum (1983) found in Danish waters that microbenthic algal production peaked at 120 g C m^{-2} y^{-1} at 0.5 m MLW, dropped to 35 g C m^{-2} y^{-1} at 2 m MLW, and decline to low values below 5 m..

The production rate of periphyton declines more rapidly than macrophytes. Thus, the total shallow (photic) substrate area in Buzzards Bay (10,380 ha, Chapter 1) overestimates the areal extent of periphyton production area, because more than 80% of this substrate is covered with eelgrass beds, rock fields, or sand flats without appreciable periphyton densities. If the remaining area has a mean production rate of 45 g C m^{-2} y^{-1}, then periphyton contribute 9 x 10^8 g C y^{-1} in Buzzards Bay.

Salt marshes

Salt marshes cover 1900 ha in Buzzards Bay (Hankin et al, 1985). These communities are productive, but they do not export appreciable amounts of organic matter (Nixon, 1980). One well studied salt marsh in Buzzards Bay has a mean annual production of 160 g C m^{-2} y^{-1} (Valiela et al., 1975), however, only 20% of its production is released into Buzzards Bay (Valiela and Teal, 1979). If this marsh is typical for the region, then the contribution of salt marshes to Buzzards Bay is 6.0 x 10^8 g C m^{-2} y^{-1}.

Relative contribution of eelgrass production in Buzzards Bay and adjoining shallow embayments

Most of Buzzards Bay is too deep to support eelgrass growth, hence eelgrass and epiphytic algae contribute only 13% of the total production in Buzzards Bay (Table 1). In contrast, eelgrass communities may account for a larger portion of total production in shallow embayments.

For example, Buttermilk Bay is a 210 ha lagoon at the north end of Buzzards Bay with a mean depth of 1.0 m (Costa, 1988; Valiela and Costa, in press), and 47 ha of eelgrass production area (Appendix III). Assuming eelgrass production rates described above, then *Zostera* production in Buttermilk Bay equals 1.6 x 10^8 g C y^{-1}.

Other producers can also be estimated as before. Algal epiphytes are very abundant in parts of Buttermilk Bay, and if the equal 40% of *Zostera* production (Penhale, 1977), they account for an additional 0.7 x 10^8 g C y^{-1}. In a shallow, enriched Rhode Island lagoon, Nowicki and Nixon (1985) estimated phytoplankton production to 120 g C m^{-2} y^{-1}. If Buttermilk Bay has similar rates of production, then phytoplankton produce 2.5 x 10^8 g C y^{-1}.

Drift algae are abundant in some areas of Buttermilk Bay, (Costa, 1988). Algal biomass in 1985 was 77 g dry wt m^{-2} (n=8, se=22) in a transect from mid-bay to Red Brook. If annual production is 6x summer biomass then annual production is ~500 g C m^{-2} y^{-1}. This transect was centered near a major source of nutrients, and probably overestimates algal abundance in the Bay. In Buttermilk Bay, drift algae occur mostly in quiescent areas, depressions, or tangled within eelgrass shoots, especially near nutrient sources. Total drift algae area was

conservatively estimated to be 20% of eelgrass cover, and therefore contributes 0.5×10^8 g m^{-2} y^{-1} to Buttermilk Bay.

Attached algal production in Buttermilk Bay is negligible, because rock and cobble are common in only a few areas. Altogether there is less than 6.5 ha of attached algae habitat in this Bay, or 0.3 g C $\times 10^8$ y^{-1}.

Epipelic periphyton are more important in Buttermilk Bay because there are ca. 50 ha of unvegetated mud bottom where periphytic algae may be abundant. Assuming production rates of 100 g C m^{-2} y^{-1}, then this component may equal 0.5×10^8 g C y^{-1}.

Based on these estimates, eelgrass beds and their epiphytes account for 40% of all production in Buttermilk Bay (Table 2).

Table 1. Eelgrass production in Buzzards Bay compared to estimates of other producers.

Salt marsh production for Falmouth and the Elizabeth Islands was based on the area salt marsh adjoining Buzzards Bay (from Hankin et al., 1985).

Component	Production ($g\ C\ y^{-1} \times 10^8$)	Percent of Total
Phytoplankton	588	82
Eelgrass	78	11
Eelgrass epiphytes	15	2.1
Other periphyton	9.0	1.3
Macroalgae	20	2.8
Salt marshes	6.1	0.9
TOTAL	716	

Table 2. Eelgrass production in Buttermilk Bay compared to estimates of other producers.

No estimates of salt marsh production were made.

Production Component	$(g\ C\ y^{-1} \times 10^8)$	Percent of Total
Phytoplankton	2.4	40
Eelgrass	1.6	27
Eelgrass epiphytes	0.7	12
Drift algae	0.5	8.3
Macroalgae	0.3	5.0
Other periphyton	0.5	8.3
TOTAL	6.0	

Chapter 3

Evidence for long-term changes in eelgrass (*Zostera marina* L.) abundance in Massachusetts in sediment cores

Introduction

Analysis of core sections from coastal marine depositional environments shows great promise for assessing the impact of anthropogenic and natural disturbances that have taken place during recent centuries. For example, in Chesapeake Bay, sediment cores were used to document increases in algal biomass, nutrient loading, and sediment deposition, and decreases in submerged aquatic vegetation as a result of human development (Brush, 1984; Brush and Davis, 1984; Davis, 1985; Orth and Moore, 1983b). In this paper I document past cycles in eelgrass abundance with cores from bays on Cape Cod and Buzzards Bay, Massachusetts.

In temperate waters, eelgrass populations undergo major fluctuations in abundance due to disease, storms, ice scour, and pollution (Harlin and Thorn-Miler, 1981; Orth and Moore, 1983b; Robertson and Mann, 1984, den Hartog, 1987). For example, the wasting disease destroyed at least 90% of all eelgrass in the Western Atlantic during 1931-32 (Rasmussen, 1977; den Hartog, 1987) and less dramatic declines of eelgrass were reported along the eastern seaboard of the US in 1894, in New England in 1908, and in Popponesset Bay (adjacent to Waquoit Bay) during 1915 (Cottam, 1934). In recent decades, nutrient

loading has been implicated in local eelgrass declines because added nutrients elevate the biomass of epiphytes on eelgrass and phytoplankton, both of which decrease light availability, and ultimately cause the death of eelgrass beds (Orth and Moore, 1983b; Sand-Jensen and Borum, 1983).

Most macrophyte seeds in marine and estuarine environments sink. Davis (1985) examined the morphology, density, and settling velocities of seeds produced by aquatic vegetation and concluded that most seeds are deposited in or near the beds that produced them, even in moderate currents. Because eelgrass seed coats are resistant to decay and remain in the sediment even if a seed germinates, they are good indicators of eelgrass abundance and distribution over many decades or centuries. Eelgrass leaf and rhizome fragments are also present at considerable depths in cores, but are less quantitative indicators of eelgrass abundance.

Cores can be dated by pollen profiles, radioisotopes, or by remnants of human activity such as coal particles or other refuse (Brush, 1984; Brush and Davis, 1984, Redfield, 1972). Changes in diatom community, invertebrate abundance, and chemical composition not only demonstrate changes in coastal ecosystems, but can also be used to date core sections if some information is already available on historical changes in the environment. Generally cores are meaningful only when taken in depositional environments, remote from high current velocities, wave action, dredging, or construction (Davis, 1984).

When cores are not dated independently, a realistic range for sedimentation rates for depositional environments can be approximated

from the depth of the wasting disease event, plant community changes, sea level rise, and cores taken elsewhere. For example, tidal records inicate that sea level is rising relative to the land in the northeast U.S. at a rate of 2-3 mm y^{-1} during the last 2 centuries (Emery, 1980). Because depths of local undredged, quiescent areas have changed little on maps during the last 100 years, sedimentation in many areas, are probably within a factor or two of the sea level rise rate. Some cores show community transitions from recent *Zostera* beds to *Ruppia* beds to the salt marsh grass *Spartina* with increasing depth, indicating that overall, sediment deposition rates were less than sea level rise rates. In Chesapeake Bay, recent sedimentation rates for cores taken in quiescent areas ranged from 2 to 10 mm y^{-1}, and higher near rivers (Brush, 1984; Davis, 1985). In Boston Harbor, sedimentation rates near a sewage outfall were as high as 30 mm y^{-1} (M. Bothner, pers. comm.). Lower rates may be typical for undisturbed areas in bays on Cape Cod because river discharges are small. For example, if local sediment deposition is 2-10 mm year, declines in seed abundance due to the wasting disease can be expected to occur between 10 and 40 cm in cores. Of course channels, deeper basins, sites near barrier beaches, dredged areas, or streams may experience considerably higher rates of deposition or even sediment removal.

Methods

To determine regional fluctuations in eelgrass abundance, nine cores were taken in 4 bays around Cape Cod (Fig. 1). One core was taken in the north central region of Apponagansett Bay, So. Dartmouth (core

AB) at 1.4 m MLW where no eelgrass grows today. Another was taken along Goats Neck, Naushon Is. (GN) at 0.7 m MLW with a shallow eelgrass bed. Three cores taken in Buttermilk Bay, Wareham either within or adjacent to eelgrass beds: one (BB1) on the north side of the flood delta at 1.2 m MLW, one (BB2) 20 m from a marsh at 0.8 m MLW, near the north end of the bay, 60 m east of Red Brook, a small stream there, and the third (BB3) in the same area but 50 m from shore at 1.1 m MLW. Four cores were taken in Waquoit Bay, at the border of Falmouth and Mashpee. Three of the cores formed a transect from the deep east central part of the bay at 2.1 m MLW (WB1), toward the east within 0.5 km of both the eastern shore and the mouth of the Quashnet river, a large stream entering the Bay. Cores WB2 and WB3 were taken at 1.9 and 1.8 m MLW respectively, and each core was at least 200 m from the nearest core. A fourth core (WB4) was 60 m south of the northern shore of the Bay at 1.1 m.

The cores were taken underwater by pushing a 10 cm diameter PVC pipe into the sediment 40 to 80 cm, plugged, brought to the laboratory, and sectioned in 1.5 or 3 cm intervals. Sections were wet sieved into three fractions: 1-2 mm, 2-10 mm, and >10 mm, to determine the abundance of eelgrass fragments and seed coats, as well as invertebrate remains.

In Waquoit Bay today, sizable beds of eelgrass grows only near the mouth of the Bay, 1.5 km from the nearest any core and is found today. To determine if these beds contribute any seeds to the area where the core was taken, 24 10 cm shallow cores were taken around this bed to determine the distribution of seed dispersion. Four cores were taken near the center of the bed at 0.9 m, 4 were taken at the deep edge of

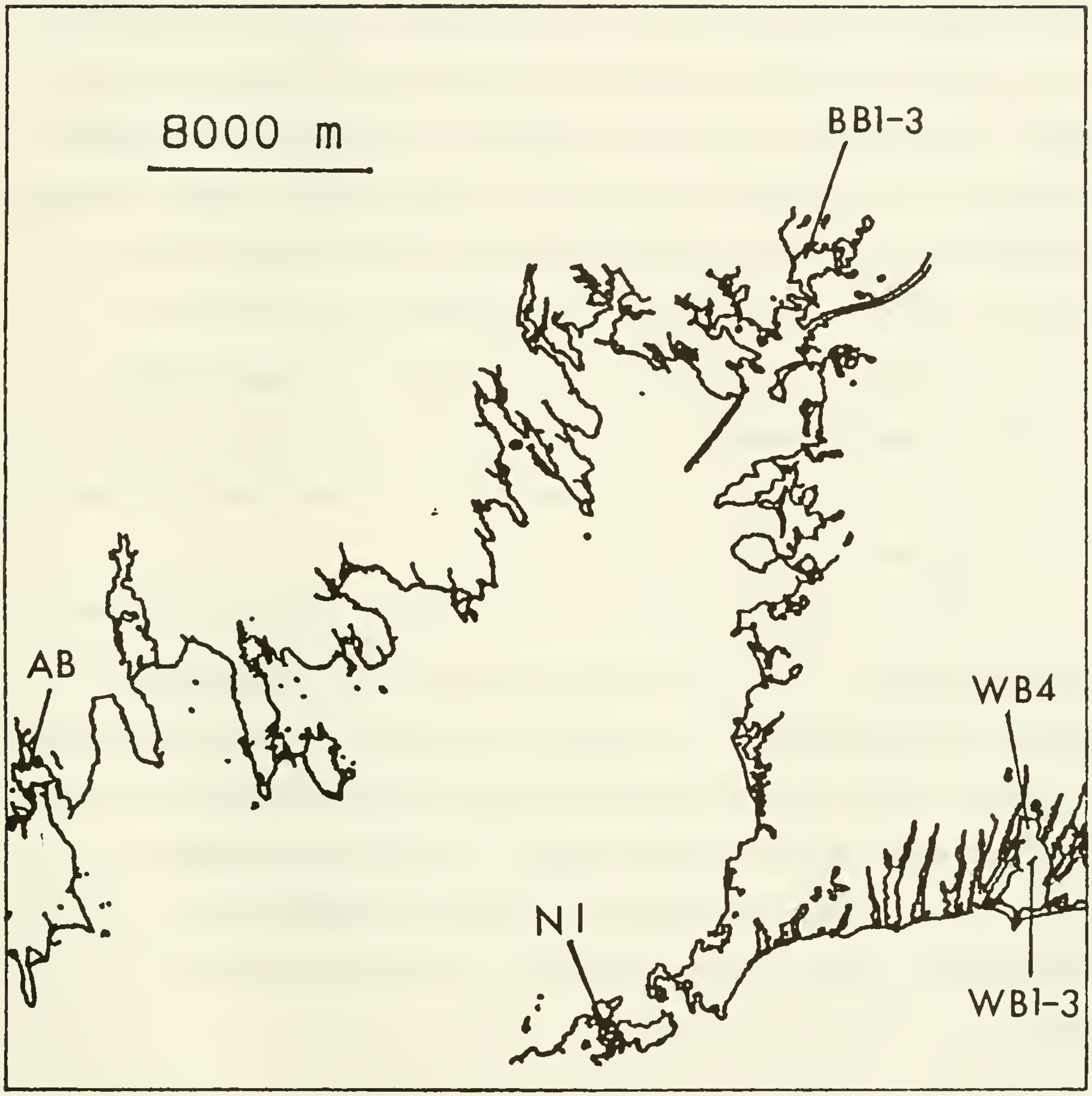

Figure 1. Location of sediment cores taken in Buzzards Bay and around Cape Cod.

The four bays examined were Apponagansett Bay (AB), Naushon Is. (NI), Buttermilk Bay (BB1-3), and Waquoit Bay (WB1-4).

Other areas

Buttermilk Bay core WB1 (taken on the north end of the flood delta) proved undesirable because 2 dense layers of sand occurred within the core indicating this environment was disturbed or altered in the past. A dense layer of sand at 15 appeared to coincide with dredging nearby that occurred between 1943 and 1951 photographs. A layer of sand at 40 cm may coincide with completion of the Cape Cod Canal nearby around 1916 which caused a change in the hydrography of the bay (Stevens, 1935). Core 2 was taken too close to shore, and rapidly graded into *Ruppia* community, then salt marsh peat. The tops of these cores, nonetheless, showed similar patterns of abundance as BB3 which showed eelgrass declines at 12, 27 and 42 cm.

In Buttermilk Bay, eelgrass was widespread prior to the wasting disease (Stevens, 1935, 1936), and photographs show a broad recovery during the 1940's and 1950's. Eelgrass was somewhat less abundant near this core during the early 1960's, but has expanded since then. Given these observations, and assuming rates of deposition are similar to Waquoit Bay, it appears that the wasting disease began at 27 cm. If sedimentation rates were similar prior to the wasting disease, the earlier decline occurred ≈1903.

The core at Naushon Island was insufficiently deep for comparison to the other cores. This core was taken in a quiescent area 20 m from an undisturbed, protected shore, with no local riverine inputs, therefore sediment deposition rates may be very low here, and the wasting disease may account for the decline in seed abundance at 18 cm. This is supported by the observation that eelgrass declines at the

that most seeds land near the beds that produced them, and the contribution of seeds by the existing beds in Waquoit Bay are negligible where the seed profile cores were taken. These results are also consistent with exponential declines in seed densities observed in wind dispersed seeds from trees (Sharpe and Fields, 1982).

All the cores documented major fluctuations in eelgrass abundance in the past reflecting local fluctuations in abundance (Fig. 3). Because the cores taken in Waquoit Bay were all taken from stable environments, analyzed in more detail, and had more replicates, they will be discussed first.

Waquoit Bay

The cores from the Waquoit Bay transect (WB1-WB3) each showed three major peaks (B-D) in eelgrass abundance, separated by periods when eelgrass was absent (Fig. 3, WB2 not shown). The depth of each these peaks was progressively deeper along the transect toward the Quashnet River and eastern shore, indicating higher rates of sediment deposition from either of these sources. Biogenic depositional markers demonstrate that these three peaks are identical. Three major mortalities of bay scallop *Argopectin* juveniles between peaks B and C occur in the three cores (S's in Fig. 3). For example, in the 31.5-33.0 cm section in core WB2 (117 cm^3), 42 valves *of Argopectin* juveniles were found that lacked signs of predation. Furthermore the snail *Bittium alternatum* is abundant on the bottom of Peak B and top of Peak C on all three cores, with densities exceeding 3 *Bittium* per cm^3 in some sections. A large population of the mud snail *Nassarius* sp. appear in eelgrass peak D of

cores WB2 and WB3 as well, which were sampled to greater depths than core WB1.

The seed profile in the core taken along the northern shore of Waquoit Bay (WB4, Fig 3) appears dissimilar from the mid-bay cores, nonetheless, the *Argopectin* mortality, *and Bittium* and *Nassarius* peaks indicate that the three lower, less distinct peaks in this core correspond to peaks B-D in cores WB1-3. In addition, eelgrass grew later here (peak A), in this shallow, nearshore area than the deep cores.

The dates of these changes in eelgrass abundance can be deduced from the recent history of eelgrass changes in Waquoit Bay. Today no eelgrass grows near any of the cores, and is largely restricted to the flood delta in the south end of the Bay. The wasting disease of 1931-32 destroyed eelgrass throughout the region, but the cores demonstrate that eelgrass grew even in the deepest parts of the Bay in the past. The photographic record (1938-present) indicates that in 1938 eelgrass was absent throughout the deep areas of the Bay, but grew abundantly nearshore, especially along the eastern margin of the bay, as well as near core 4. In the 1940's eelgrass began to recolonized the central portion of the Bay, and was very abundant there by the late 1950's. After 1965, eelgrass began to disappear in the deepest parts of the bay, and by the mid-1970's had disappeared from the along the Bay margins as well, including near core 4.

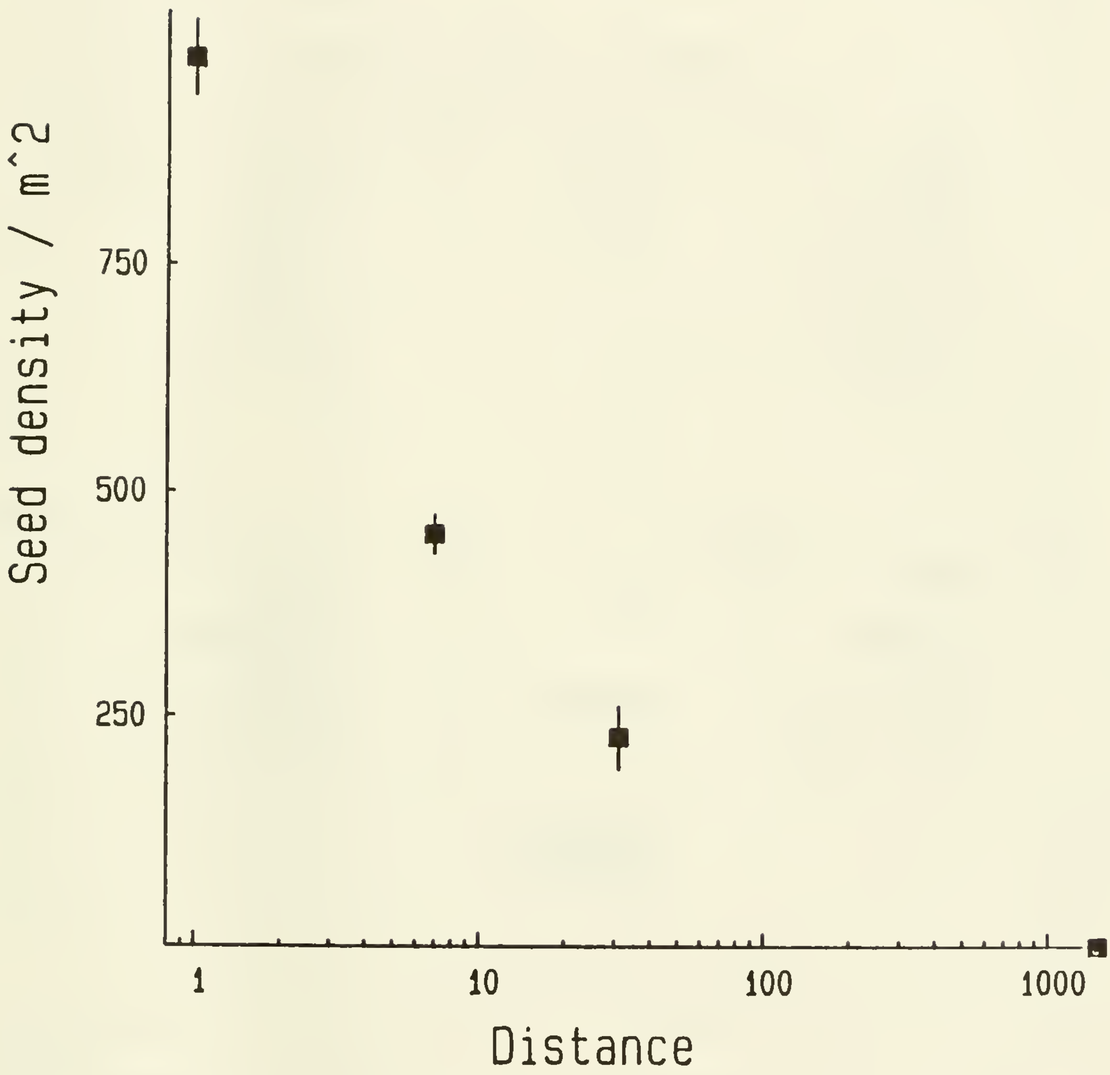

Figure 2. Seed densities distribution in Waquoit Bay.

Distance values were transformed Log(x+1). Samples were taken north of eelgrass on the flood delta at the mouth of the Bay, Ø = within the bed.

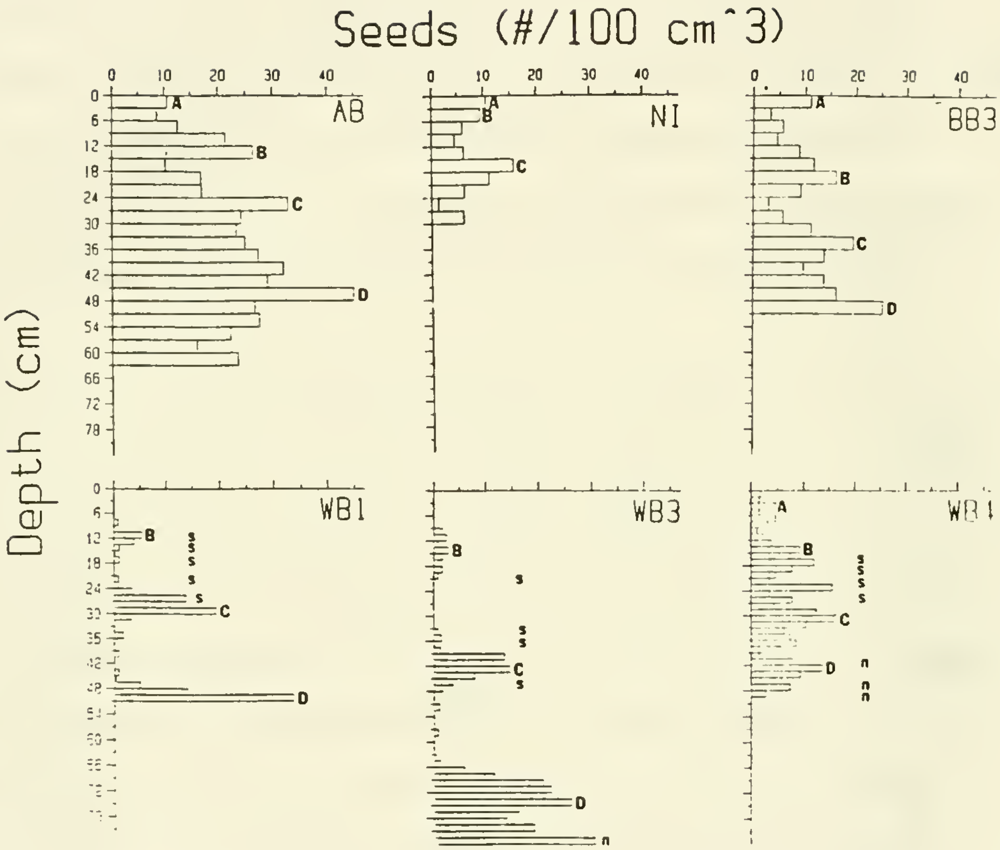

Figure 3. Sediment core eelgrass seed profiles in 4 Bays.

Apponagansett Bay (AB), Naushon Is. (NI), Buttermilk Bay (BB) and Waquoit Bay (WB). Symbols indicate peaks *Nassarius* (N) and *Argopectin* juvenile mortality (S). A-D indicate *Zostera* peaks described in text. *Bittium* peaks are not shown.

This most recent eelgrass decline appears to be to decreased light availability because of increased epiphyte growth and phytoplankton from nutrient loading (Valiela and Costa, in press), and in recent decades, dense layers of drift algae (primarily *Cladophora*, *Gracillaria*, and *Agarhdiella*, up to 70 cm thick) have been accumulating. This dense layer of algae precludes future recolonization of eelgrass because seedlings cannot survive under dense layers of unconsolidated algae.

From these observations, it appears that the decline of peak C was due to the wasting disease. Peak B documents the recovery of eelgrass in the bay during the 1950's then subsequent decline, and Peak A is present only when eelgrass persisted in recent years as was the case in the vicinity of core WB4. Based on this chronology, the scallop mortalities appear to coincide with the three major hurricanes to impact this region during this century: 1938, 1944, and 1954. Scallop populations have been historically high in Waquoit Bay, accounting for 80% of the fishery in all of Falmouth (Alber, 1987). The bay is large and shallow, which may contribute to the burial of spat during storms.

Within each core, the depositional markers are consistent, but differences exist at each station. The depth of peak B and the most recent *Argopectin* mortality in this core suggests that the recent depositional rate in the north end of the bay (WB4) is similar to the mid-Bay cores (5.5 mm y^{-1}), but slower between 1932 and 1954 (4.8 mm y^{-1}) than comparable periods in the mid-Bay (5.5 mm y^{-1}). During earlier periods at this station the depositional rate here was even lower because peak D is nearer the surface than elsewhere. The more recent increases in sedimentation rate at core WB4 may be due to the

enlargement of the flood delta of a small lagoon nearby (Quahog Pond). On recent photographs, this delta is more prominent because of loss of eelgrass cover, and may have expanded during the last 40 years. Boat activity in the Bay has increased appreciably in recent decades and the resulting sediment resuspension may have contributed to increases in sedimentation there.

The loss of resolution in the seed peaks in core WB4 may be due to the slower deposition rates, increased disturbance from wave action nearshore, or greater contribution from shallow annual beds that persisted between declines.

The highest rates of sedimentation occurred at the station nearest to the Quashnet River (WB3) during the period 1932-1954 (8.8 mm y^{-1}) which was higher than stations further offshore (5.5) during the same period, and higher than observed later at the same station (1954-1987, 6.4 cm y^{-1}). The higher rates may have been associated with cranberry bog construction and use along the Quashnet River during the earlier period.

Using the biogenic markers and rates of sedimentation, the date of recent and earlier declines can be calculated. If the most recent scallop mortality is used as a marker, the date of the decline in peak B can be calculated for each core. At the deepest mid-Bay station (WB1), eelgrass disappeared first ~1961, then at the shallow mid-bay stations in ~1971 (core WB2), ~1973 (WB3, Fig. 4). In the north end of the Bay, eelgrass disappeared ~1965. The loss of eelgrass in deeper and upper bay stations first, supports the hypothesis that these declines were associated with declining light availability, because this pattern has

been observed elsewhere nutrient loading has increased (Orth and Moore, 1983b).

If deposition rates prior to the wasting disease are equal to post-disease rates, then the date of the first pre-wasting disease decline appeared circa 1902-1906 for all four Waquoit Bay cores. In addition, the two cores (WB3 and WB4) with the earliest depositional records indicate an even earlier decline circa 1870-1890.

The cause of the 1902-1906 has several plausible explanations. Some shallow coastal lagoons on Cape Cod close periodically, and a closure of Waquoit Bay would reduce mouth would reduce salinity in the Bay and possibly change water transparency. It is unlikely that Waquoit Bay had become fresh during the last 100 y because all nautical charts to 1865 Waquoit Bay with a prominent channel at the mouth, and marine species persist throughout the core including when eelgrass is absent.

Another possibility is that some other factor caused water transparency to decline, and eelgrass disappeared from the deep areas where the cores were taken. This seems unlikely, because prior to 1931, there was little development around the Bay. Farms were common, but levels of fertilization were far less prior to the use of manufactured fertilizer. Cape Cod has undergone considerable deforestation and conversion to farmland in the past, and topsoil runoff on nutrient release from soils could have been a contributing factor, but this too seems unlikely because river flow into the bay is nominal.

Instead the most plausible explanation is that these declines coincide with the eelgrass population collapse reported by Cottam in 1908 or 1894.

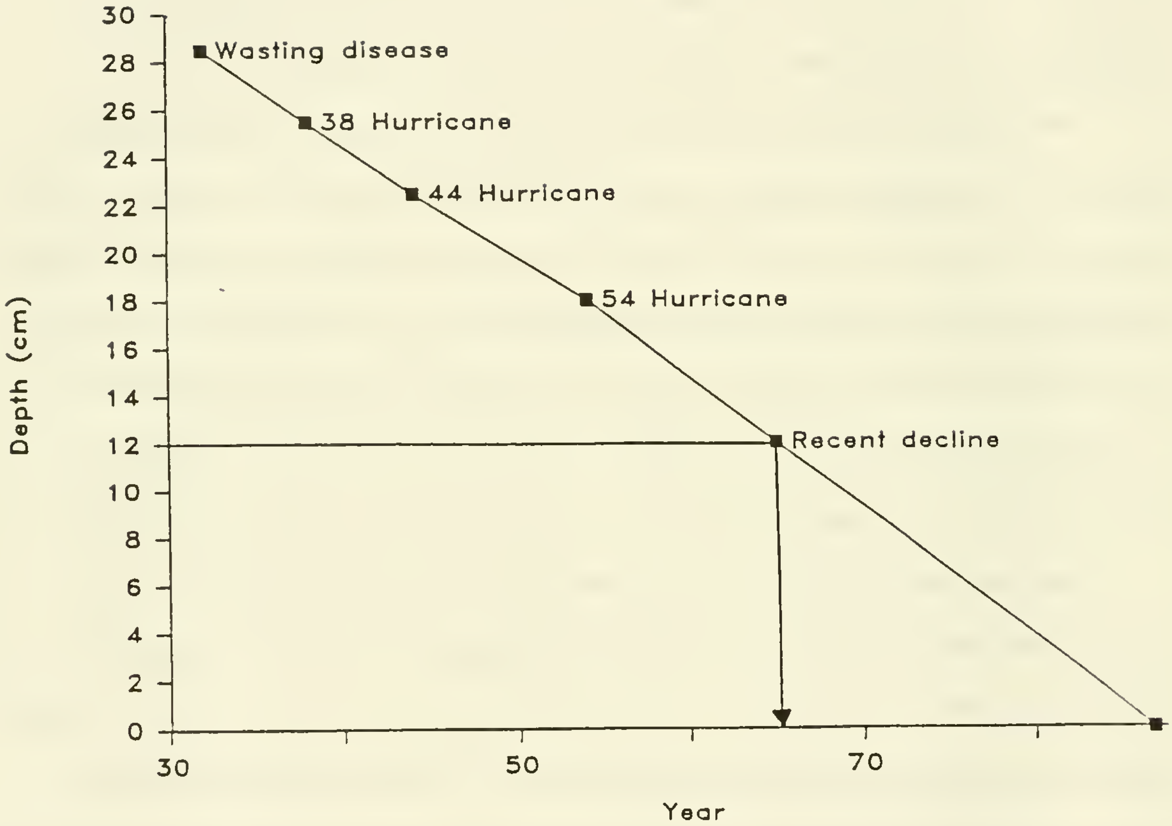

Figure 4. Depth of depositional markers in core WB4.
The date of the most recent decline was estimated from its depth and deposition rates.

Other areas

Buttermilk Bay core WB1 (taken on the north end of the flood delta) proved undesirable because 2 dense layers of sand occurred within the core indicating this environment was disturbed or altered in the past. A dense layer of sand at 15 appeared to coincide with dredging nearby that occurred between 1943 and 1951 photographs. A layer of sand at 40 cm may coincide with completion of the Cape Cod Canal nearby around 1916 which caused a change in the hydrography of the bay (Stevens, 1935). Core 2 was taken too close to shore, and rapidly graded into *Ruppia* community, then salt marsh peat. The tops of these cores, nonetheless, showed similar patterns of abundance as BB3 which showed eelgrass declines at 12, 27 and 42 cm.

In Buttermilk Bay, eelgrass was widespread prior to the wasting disease (Stevens, 1935, 1936), and photographs show a broad recovery during the 1940's and 1950's. Eelgrass was somewhat less abundant near this core during the early 1960's, but has expanded since then. Given these observations, and assuming rates of deposition are similar to Waquoit Bay, it appears that the wasting disease began at 27 cm. If sedimentation rates were similar prior to the wasting disease, the earlier decline occurred ~1903.

The core at Naushon Island was insufficiently deep for comparison to the other cores. This core was taken in a quiescent area 20 m from an undisturbed, protected shore, with no local riverine inputs, therefore sediment deposition rates may be very slow here, and the wasting disease may account for the decline in seed abundance at 18 cm.

This is supported by the observation that eelgrass declines at the bottom of the core coincide with large increases in *Ruppia* seeds, which exceed 1 seed per cm^3. This suggests that either the environment was shallow or more estuarine during deposition. Alternately, *Ruppia* replaced eelgrass when the latter disappeared, because both species occupy the habitat today, and *Ruppia* is a relatively minor component. This seems unlikely, however, because *Ruppia* did not become abundant during the most recent decline. If rates of deposition prior to the wasting disease were similar to post disease rates, then the earlier decline at 27 cm occurred ~1906.

The Apponagansett Bay core is least typical. Eelgrass seems to be persistent in the bay with minor declines at 60 and 33 cm, until a major decline at 21 cm. Subsequently eelgrass recovered, then again declined. This pattern agrees with other evidence: eelgrass is abundant in the bay on nautical charts from the 19th century, eelgrass was destroyed in 1931-32, then showed recovery on aerial photographs during the 1950's and 60's, then disappeared again. In 1985, no eelgrass was found in the inner Bay. The most recent loss of eelgrass appears due to declining water quality from nutrient loading or increased turbidity form sediment resuspension by boats (Costa, 1988).

If the wasting disease occurred 21 cm here, and sedimentation rates are constant, then the minor declines at 33 and 60 cm would coincide with 1902 and 1834.

Discussion

Based on the estimated sedimentation rates and seed densities, seed deposition rates were as high as 2000-6000 m^{-2} y^{-1} in Waquoit Bay, which is somewhat higher than the mean deposition of new seeds measured at the mouth of that Bay (≈1000 seeds m^{-2} y^{-1}). This difference may not be significant because there considerable variability in the density of recently produced seeds in surface cores within beds. Similarly, cores from the other bays suggest that the seed deposition rates generally peak between 1500-2500 seeds m^{-2} y^{-1}. These rates of seed deposition are consistent with seed production rates measured elsewhere (Thayer et al., 1984), and with rates that I have measured locally (up to 15,000 seeds m^{-2} y^{-1}).

Other factors may contribute to different seed deposition rates in eelgrass beds. Environmental conditions have a strong effect on the expression of flower abundance in eelgrass, and therefore seed production (Phillips et al., 1983). Some eelgrass beds produce mostly reproductive shoots and others produce mostly vegetative shoots, and there is a high degree of consistency for beds in a particular habitat (Phillips et al.,1983; Keddy, 1987). For example, Allee (1923b) noted that eelgrass beds in the Northwest gutter of Uncatena Island in the Elizabeth Islands always have high flower densities. These beds continue to have high flower densities today (pers. obser).

Thus, eelgrass seed coat abundance is a good indicator of local, relative eelgrass abundance, but not necessarily an absolute indicator of biomass or production. Undoubtedly there are yearly differences in seed production, but because these core sections equal 2.5 - 8 years of

deposition, this variation should be diminished. Processes that bioturbate the sediment, such as sediment ingestion and excretion by worms, blur the stratigraphic record of some sediment markers such as radioactive isotopes or pollen profiles. These processes are relatively unimportant in altering the eelgrass record because eelgrass seeds are too large to be ingested by most deposit feeders.

The rates of seed deposition, sedimentation rates, depths of deposition markers, and photograph documentation are all consistent with the interpretations given here, but additional dating methods should be employed to verify actual dates. Nonetheless, these results demonstrate eelgrass populations in each bay have shown sizable fluctuations in the past, and that some of the trends are regional. Some of these fluctuations like the wasting disease of 1931-32 appear clearly in depositional record. Furthermore, reports of declines prior to the wasting disease are substantiated because all the cores show a decline around the turn of the century. If sedimentation rates were similar prior to the wasting disease, as after, then the declines in each bay most closely match the 1908 eelgrass decline in New England reported by Cottam (1934). It is plausible that sedimentation rates prior to the disease were lower, because the frequency of intense storms increased after 1930 (Aubrey and Speer, 1984; Zeeb, 1985), which could have also increased sedimentation rates. If so, then these declines coincide with the 1894 decline reported by Cottam (1934).

The two bays with evidence of nutrient loading effects (Waquoit and Apponagansett Bays) show eelgrass declines that are well documented in the photographic and sedimentary record. Therefor, the use of

sediment cores show promise in assessing the impact of anthropogenic disturbance in coastal depositional environments.

Chapter 4

Historical Changes in eelgrass (*Zostera marina* L.) abundance in Buzzards Bay: Long term patterns and twelve case histories

Introduction

During the 1930's, the "wasting disease" destroyed virtually all eelgrass (*Zostera marina* L.) along the coasts of eastern North America and Europe (Rasmussen, 1977). Recovery by eelgrass populations from this catastrophic disturbance was slow and took 30 or more years in most areas (den Hartog, 1987). Superimposed on this long term cycle of collapse and recovery are more recent, local, short and long-term losses of eelgrass due to declining water quality, storms, dredging, shellfishing, and other sources (Orth and Moore, 1983b, Kemp et al., 1983; Thayer et al., 1975). Too often, documentation of declines and recolonization of eelgrass have been qualitative and this has hindered an understanding of the mechanisms or relative importance of different disturbances on eelgrass distribution and abundance. To understand or predict the impact of these disturbances, it is necessary to have data of present-day eelgrass cover, historical changes, or data from comparable areas.

The main objective of this paper is to document long-term changes in eelgrass abundance in areas of Buzzards Bay that have had different histories of anthropogenic and natural disturbances. From this information, inferences can be made on the relative impact and return

time of eelgrass populations impacted by disturbances of different scale and intensity. Because the effects of the wasting disease were so longlasting, and because new outbreaks of the disease have been reported, I also reassess the causes and impact of the wasting disease in Buzzards Bay. In particular I examine the relevance of the temperature hypothesis to this and earlier declines in eelgrass populations.

I have documented changes in eelgrass abundance from aerial photographs, written reports, old charts, observations of local residents, and in a few cases, sediment cores. This approach has been used elsewhere, most notably in Chesapeake Bay, where the loss of eelgrass and other submerged macrophytes in recent years has been documented (Brush and Davis, 1984; Davis, 1985, Orth and Moore, 1983b). I have based my interpretation of the historical record on factors that limit eelgrass distribution and the local history of natural and human disturbances.

Factors limiting eelgrass distribution

Eelgrass may be absent from an area because of factors that prevent growth, or because eelgrass has not recovered from disease or other disturbance. The most important factor limiting the geographic distribution of eelgrass is light (Dennison, 1987; Wetzel and Penhale, 1983; Sand-Jensen and Borum, 1983). In clear temperate waters, eelgrass grows to 11 m MLW or more, but to less then 1 m MLW in some turbid or enriched bays (Sand-Jensen and Borum, 1983). The deepest reported growth of eelgrass was reported by divers at 45 m in Southern California

(Cottam and Munroe, 1954). When there is sufficient light available, the next most important factors limiting eelgrass distribution are physical energy, salinity, and temperature.

Eelgrass is euryhaline, but is usually not found where salinities persist below 5 ppt (Sand-Jensen and Borum, 1983; Bieble and McRoy, 1971). In Buzzards Bay and on Cape Cod, there are few sizable inputs of freshwater, and eelgrass distribution is limited by salinity in only a few areas.

Physical energy also controls eelgrass distribution, but eelgrass can has the ability to grow in diverse habitats. For example, eelgrass beds can grow at sustained current velocities up to 150 cm sec^{-1}, and may tolerate brief exposure to higher velocities (Fonseca et at., 1982a, 1983). Eelgrass beds can tolerate considerable wave exposure as well, but are generally not found in the surf zone. Thus, on exposed coasts eelgrass may not grow above 2 m MLW, whereas in protected areas, eelgrass may be found in the intertidal. There are exceptions: clumps of eelgrass can be nestled between boulders or in intertidal pools in high energy areas (pers obs).

Eelgrass is eurythermal, and can survive between the freezing point of seawater and 40° or more, therefore temperature is important only in shallow stagnant waters such as salt ponds and salt marsh pans which are exposed to wide temperature fluctuations or appreciable icing (e.g. Keddy, 1987). In these and other shallow areas, freezing and ice scour may remove beds (Robertson and Mann, 1984), and annual populations of eelgrass are most common in these types of habitats.

The wasting disease

The "wasting disease" of 1931-32 greatly depleted eelgrass (*Zostera marina* L.) populations in the North Atlantic, and most populations did not recover for many decades (den Hartog, 1987). Other declines were reported in 1890 in the Eastern U.S., and in 1906 in New England (Cottam, 1934). The loss of eelgrass in the 1930's resulted in declines in many animal populations, as well as increased erosion on some beaches (Thayer et al., 1984; Rasmussen, 1977). Because effects of this decline were so profound and longlasting, and because new outbreaks of the disease have been reported (Short et al., 1986), there has been concern about new collapses of eelgrass populations.

The wasting disease was documented by numerous observers, and its causes and effects have been periodically reassessed (Stevens, 1939; Milne and Milne, 1951; Rasmussen, 1977; den Hartog, 1987). Before the wasting disease, eelgrass populations were generally described as dense and widespread in temperate waters (den Hartog, 1987). In the western Atlantic in the summer of 1931, black and brown spots appeared on eelgrass leaves, spread to other leaves and shoots; leaves became necrotic and plants died. The outbreak of the disease continued the following year, and by the end of 1932, the vast majority of eelgrass populations on the east coast of North America disappeared. Events were similar in Europe, but the declines in eelgrass abundance began in 1932, and continued in 1933 (Rasmussen, 1977). Neither eelgrass populations in the Pacific, nor other *Zostera* spp. endemic in Europe were affected by the disease.

Assessment of loss of eelgrass were generally qualitative because most eelgrass populations were not previously mapped, and descriptions were limited to areas where shellfish wardens or researchers had been familiar. Observers described how eelgrass had formerly covered the bottom of certain bays before the disease, whereas after the disease, eelgrass was no longer present. It is generally believed that the disease destroyed at least 90% of all existing eelgrass beds throughout Atlantic coasts, and in many areas destruction was complete (den Hartog, 1987). Observations in Denmark substantiate this view, because eelgrass beds were studied and mapped during the early in the 20th century. Eelgrass populations around Cape Ann Massachusetts disappeared (Cottam 1933, 1934). In Buzzards Bay, eelgrass virtually disappeared from Buttermilk Bay, Bourne (Stevens, 1935, 1936), Sconticut Neck, Fairhaven, and West Falmouth (Lewis and Taylor, 1933), and around Woods Hole (Stauffers, 1937). Stevens et al. (1950) estimated that less than 0.1 % of pre-existing eelgrass bed cover in upper Buzzards Bay survived the disease.

Since the wasting disease, eelgrass populations slowly recovered on both sides of the Atlantic, and greatest rates of expansion occurred during the 1950's and 1960's (den Hartog, 1987; ref), but some areas are still expanding today (den Hartog, 1987).

Considerable controversy has arisen as to the cause of the wasting disease. In the 1930's, the cellular slime mold, Labarynthula, was associated with the wasting disease, however, it was unclear at the time whether the slime mold was the cause of the disease or merely a symptom of a disease caused by pollution, abnormally warm or dry weather, or

some other physical factor or biological agent (Cottam, 1934; Milne and Milne, 1951). Recently, Short (pers. comm.) has demonstrated that Labarynthula was the biological cause of the wasting disease, but what triggered the catastrophic decline in 1931-32 remains unclear.

Rasmussen (1977) presented an analysis of the wasting disease that has been widely accepted. He rejected all previous hypotheses concerning the disease except the effect abnormally warm temperatures which were elevated during the early 1930's. Water temperatures were not exceptionally warm in all areas during that period, but came after a prolonged cool period. This warm period resulted in the elevation of mean water temperatures by several °C that stressed eelgrass, making it more susceptible to a pathogen. He explained the occurrence of the disease one year later in Europe was because the warming period occurred one year later there as well.

Rasmussen acknowledged that *Zostera* can tolerate wide temperature ranges throughout its geographical range, but suggested that eelgrass populations are adapted to local temperature conditions and were sensitive to these changes. He suggested that the survival of eelgrass populations near streams and other sources of freshwater may have been due to higher rates of germination in annual populations near these sources or that the disease organism was stenohaline.

The temperature hypothesis cause of the decline of 1931-32 has been criticized for several reasons, and these are discussed below. Past declines of eelgrass have also been reported, such as in 1894 in the eastern U.S., around 1908 in New England, and in 1916 in Poponesset Bay, Cape Cod (Cottam, 1934). These events, perhaps due to disease,

were not as catastrophic as the 1931-32 decline, and were not well documented.

Anthropogenic and natural disturbances

Light, wave and current energy, salinity, and temperature limit eelgrass distribution, but many natural and anthropogenic disturbances of varying scale and frequency destroy eelgrass beds. Certainly the most important natural disturbance during this century was the wasting disease, but other natural disturbances such catastrophic storms, periodic storms, sediment transport, ice damage, and grazing play an important role in controlling eelgrass abundance (Harlin et al., 1982; Jacobs et al., 1981; Kirkman, 1978; Orth, 1977; Rasmussen, 1977; Robertson and Mann, 1984).

Anthropogenic disturbances that may destroy seagrass beds include physical disturbances (dredging, groin construction, shellfishing, propeller damage), toxic pollution, and degradation of water transparency from nutrient enrichment, topsoil runoff, and activities that resuspend sediments (Cambridge, 1979; Kemp et al., 1983; Orth and Moore, 1983b; Orth and Heck, 1980; Sand-Jensen and Borum, 1983; Thayer, et al., 1975).

The cause of a particular loss of eelgrass can often be inferred from the pattern and rate of loss, the rate or lack of recovery, and the local history of an area. Of all the anthropogenic an natural disturbances affecting eelgrass populations, severe climatological events and declining water quality have had the greatest impact on

eelgrass abundance in southeastern Massachusetts, and are discussed in greater detail below.

Storm damage and ice scour

Natural physical disturbances such as storms, ice scour, and sediment erosion affect large scale patterns of seagrass distribution (Harlin et al., 1982; Kirkman, 1978; Robertson and Mann, 1984). Aubrey and Speer (1984) and Zeeb (1985) documented that hurricanes in 1938 and September, 1944 had the greatest impact on Cape Cod during this century, and these and other major storms affect this region are listed in Table 1.

Ice scouring, can have a great impact on eelgrass abundance in shallow water, but because it does not greatly impact human activity locally, it has not been well documented. Periodically, Buzzards Bay accumulates considerable ice cover that may extend several miles offshore in places, and ice thickness may exceed 30 cm in some poorly flushed areas where icing is more frequent (pers. obs. and press reports). Years in which ice scour was appreciable can be determined from winter water temperature data because water temperature correlates well with reported ice accumulation (Wheeler, 1986, and other sources). In general, years in which mean February water temperatures (c.f. fig 16) is below -0.5 °C in Woods Hole, ice accumulation in Buzzards Bay is appreciable. These years are summarized in Table 1.

Table 1. Major meteorological disturbances in Southeastern Massachusetts since 1938. The storms are roughly ranked in terms of severity (from Zeeb, 1985; Aubrey and Speer, 1984, and other accounts) Ice accumulation was based on mean February temperature (Bumpus, 1957; NOAA, 1973) and other documentation.

Date		Event	Severity
26 September	1938	Hurricane	extreme
Winter	1940	Ice accumulation	severe
Winter	1941	Ice accumulation	moderate
Winter	1944	Ice accumulation	moderate
Winter	1944	2 storms	strong
September	1944	Hurricane	extreme
Winter	1945	6 storms	strong
Winter	1945	Ice accumulation	moderate
Winter	1948	Ice accumulation	moderate
September	1954	Hurricane	severe
Winter - Spring	1958	>12 storms	moderate-strong
September	1960	Hurricane	strong
January	1961	Blizzard	moderate
Winter	1961	Ice accumulation	moderate
Winter	1963	Ice accumulation	moderate
February	1976	Storm	moderate
Winter	1977	Ice accumulation	severe
February	1978	Blizzard	moderate
Winter	1978	Ice accumulation	moderate
Winter	1981	Ice accumulation	moderate
Winter	1984	Ice accumulation	moderate

Based on Table 1, the years 1938, 1944-1945, 1954, 1960-1961, and 1977-1978 had the greatest storm intensity or combination of disturbances that could have impacted eelgrass abundance. Undoubtedly, wind direction, orientation of the shore, path of storm, and local hydrography had a great effect on the local impact of these events, and smaller storms and wave scour define some smaller patterns of eelgrass colonization and patchiness observed as well.

Declining water quality

Water quality declines result from pollution by toxic compounds, enrichment by nutrients, and increased suspended sediment loads. Nutrient loading is typically most important over large regions (e.g. Orth and Moore, 1983b), and is caused by human and livestock waste disposal, and fertilizer applications. Increased suspended sediment loading may result from dredging, topsoil runoff, shellfishing, and boating. Pollution by toxic compounds is generally localized.

Nutrient loading and sediment resuspension can have profound effects on eelgrass abundance. The lower limit of eelgrass growth is determined by the duration of light intensity above compensation (Dennison, 1987; Dennison and Alberte, 1985,1986). Hence, in a fundamental way, the distribution of eelgrass is determined by factors that affect water transparency and epiphyte densities (Sand-Jensen and Borum, 1983). Nutrient loading increases phytoplankton and algal epiphyte abundance, which in turn shade eelgrass, causing lower growth and recruitment, or death (Borum, 1985; Bulthuis and Woerkerling, 1983; Kemp et al., 1983; Sand-Jensen and Borum, 1983). Eelgrass beds often

first disappear in upper estuaries where nutrient loading is highest, and at the deep edges of beds where light limits growth (Orth and Moore, 1983b).

Along a nutrient gradient in a Danish estuary, biomass of eelgrass algal epiphytes increased 50-100 fold, and phytoplankton abundance increased 5 - 10 fold (Borum, 1985). Light attenuation by epiphytes on eelgrass shoots was 90% on older leaves in these enriched areas (Sand-Jensen and Borum, 1983). Besides shading, algal epiphytes slow photosynthesis by forming a barrier to carbon uptake (Sand-Jensen, 1977). In Buttermilk Bay, the depth of eelgrass growth decreased by 9 cm for every 1 µM increase in dissolved inorganic nitrogen in the water column (Costa, 1988).

The loss of eelgrass in enriched environments is not unique and has been reported for other submerged macrophytes in freshwater lakes and ponds (Moss, 1976; Sand-Jensen and Sondergaard, 1981; Phillips, et. al, 1978), artificial freshwater ponds (Mulligan et al., 1976), tidal estuaries (Haramis and Carter, 1983), artificial estuarine ponds (Twilley, et. al., 1985), and marine embayments (Brush and Davis, 1984; Cambridge, 1979, Cambridge and McComb, 1984; Kautsky et al., 1986; Kindig and Littler, 1980; Orth and Moore,1983b). Experiments on marine ponds containing eelgrass are now in progress in Rhode Island (S. Nixon, pers. comm.).

Alternate explanations have been offered for some eelgrass declines. For example, Nienhuis (1983) suggested that the recent disappearance of eelgrass in a Danish coastal pond was not due to epiphyte abundance, but "toxification" of the sediments from decomposing

drift algae that accumulated because of nutrient loading. Sediment suspension from topsoil runoff or boat propeller often contribute to water transparency decline and loss of eelgrass (Brush and Davis, 1984; Orth and Moore, 1983b). Even where sediment turbidity is high, however, such as parts of Chesapeake Bay, attenuation of PAR by inorganic particles is generally less than the combined effects of PAR absorption by algal epiphytes and phytoplankton (Kemp et al., 1983). Nonetheless, sediment resuspension from dredging and motor boat activity is prominent in some local bays (pers. obser.), and may significantly decrease water transparency. This phenomenon has not been quantified, but may be locally important in affecting eelgrass distribution.

In southern New England, eelgrass grows as deep as 6-12 m MLW in clear offshore waters, but only to 1-2 meters in shallow bays with poor water transparency (Costa, 1988 and below). Thus, small changes in light availability to eelgrass populations, for whatever reason, may result in larges losses of eelgrass cover.

Drift algae

Drift algae typically show conspicuous increases where nutrient loading is high, and often accumulate in poor flushed bays in layers exceeding 40 cm (Lee and Olsen, 1985; pers obs.) This accumulation may smother shellfish (Lee and Olsen, 1985) and eelgrass (pers. obser.). Locally, red algae such as *Gracillaria*, *Agahrdiella*, and *Ceramium* are most abundant, often mixed with green filamentous algae such as *Cladophora*. Many of these algae are specialized morphological varieties of their species (Taylor, 1957) which grow and reproduce on the bottoms

of bays. In more enriched areas, particularly near polluted streams or near enriched groundwater inputs, green algae such as *Ulva* and *Enteromorpha* replace the red algae that dominate less enriched areas (Lee and Olsen, 1985; Pregnall, 1983; pers. obser.). This difference in species composition can be explained by the fact red algae are effective in storing "pulses" of nutrients, whereas these green algae grow quicker under more continuous exposure to high nutrients (Fujita, 1985).

Drift material may also consist of shed eelgrass leaves and detached *Codium*. Algae that are abundant on eelgrass such as the red alga *Polysiphonia*, are abundant in drift material in these areas.

Recolonization and interpreting historical changes

Eelgrass may decline in some areas due to disturbance, but will recolonize any devegetated area, as well as newly created habitat, if conditions are conducive to lateral growth of vegetative shoots or germination and survival of seedlings. Colonization rates have been documented in transplant studies. For example, Fonseca et al. (1979, 1982b) state that full coverage can be obtained in one year by transplanting 20 shoots on a 1 m grid. Similarly high rates of expansion have been noted in other studies (Araski, 1980; Goforth and Peeling, 1979).

In related work (in prep.), I have studied the colonization of bare substrate by eelgrass using sequences of aerial photographs. From these photographs, vegetative growth rate, recruitment rate, disturbance size and frequency (= bed mortality) can be measured and these four parameters, were incorporated in a computer simulation. The results of

this model demonstrated that the colonization of bare areas by eelgrass greatly depends on colonization by new seedlings. To a lesser degree, rates of colonization depend on vegetative growth rates and levels of disturbance. Disturbance intensity, however, does affect the % cover of an eelgrass bed at peak abundance. Hence, an eelgrass bed cover in a high energy, wave swept shore, may never cover more than 50% of the available substrate due to winter storms and wave scour.

Methods

Photograph analysis

In Massachusetts, parts of the coastline have been repeatedly photographed since 1938, and these photographs were obtained from various private and governmental agencies (Appendix I). Most of these photographs were taken between late spring and fall when eelgrass is densest, but photographs taken during other periods were are also informative, particularly when mapping perennial eelgrass populations. Only one set of photographs taken prior to the wasting disease was found (Sippican Harbor, Marion, taken June of 1930).

Photographs were analyzed and interpreted as described in chapter 1. As described earlier, there are four types of vegetation that resemble eelgrass beds, but can usually be distinguished on photographs: drift algae, salt marsh peat reefs, algal covered rock fields, and shell and gravel areas where the green alga *Codium* may be abundant. *Codium*, however, is a recent introduction and was not abundant in Buzzards Bay prior to the late 1960's (Carlton and Scanlon, 1985). Similarly, drift

algae is increasing in some bays, but is absent from nearly all areas on early photographs.

Nautical charts

The presence of eelgrass on old nautical charts (especially US Coastal and Geological Survey charts), is sometimes denoted by "Grs", "Grass" or "Eelgrass". Only rarely were boundaries of eelgrass beds mapped. This documentation apparently depended greatly on the whim of the field observer or mapmaker, and indications of eelgrass appear on some maps or map editions and not on others. Furthermore, since observations were made from boats, only beds that were conspicuous from the surface (general less than 3.0 m) are recorded. Even then, to prevent map clutter, "Grs" may be written once within a bay. Thus the denotation of eelgrass on a nautical charts affirms that eelgrass was present, but the lack of denotation does not imply eelgrass was absent.

Study sites

Changes in eelgrass abundance was studied at 12 sites around Buzzards Bay: The Westport Rivers; Apponaganset Bay, Dartmouth; Clarks Cove, South Dartmouth; New Bedford inner and outer harbor; Nasketucket Bay, Fairhaven; East Bay, West Island, Fairhaven; Sippican Harbor, Marion; Great Neck, Wareham and the Wareham River Estuary; Buttermilk Bay, Bourne and Wareham; Megansett Harbor, Bourne and Falmouth; Wild Harbor, Falmouth; and West Falmouth Harbor. In addition, data from another site on Cape Cod (Waquoit Bay) was included because this bay has had prominent declines in eelgrass. These sites had different histories

of anthropogenic and natural disturbances which are detailed in the results section along with their description.

Results

Westport Rivers

The East and West Branch of the Westport Rivers form the largest estuary in Buzzards Bay and historically have provided a substantial coastal fishery (Fiske et al. 1968, Alber, 1987). The land around the Westport Rivers is rural with considerable agricultural development. This agricultural land is used for both crops and livestock and residential sewage disposal consists of septic tanks. The northern end of the East Branch of the Westport River has been closed to shellfishing due to fecal contamination (Alber, 1987).

Most fresh water enters through the East Branch of the Westport River (Fig. 1). Riverine inputs into this Branch declined during the early 1960s because of construction of the Calamut dam and Intestate Highway 195. The mouth of the estuary is moderately well flushed and experiences a 0.9 m tidal range, but residence times for different sections of the estuary have not been calculated. Photographs and observations of residents indicate there has been considerable meandering of the channels and migration of sand flats within the bay, especially near the mouth.

No early documentation on eelgrass abundance was discovered, but some residents recall that eelgrass was far more abundant in the past than its present-day maximum, and eelgrass was virtually eliminated by

1932. Since then, eelgrass has slowly recovered and during the 1980's has shown dramatic increases in abundance.

The recovery of eelgrass in the Westport rivers has not been steady, and like several other shallow embayments in Buzzards Bay, there have been great fluctuations in eelgrass abundance during the last 50 years. Because of insufficient spatial and temporal coverage of aerial photographs, poor image quality, or water transparency, changes in eelgrass abundance could not be quantified for the entire estuary. Nonetheless, a brief description of available photographs demonstrate some features of changing eelgrass abundance in this estuary.

The earliest photograph (13 December 1938) has poor image quality, high water turbidity, and taken near high tide. There is virtually no eelgrass apparent on this photograph, and it is unclear if the absence of eelgrass is an artifact of poor imagery, or due to the September 26 hurricane. A few shoals near the mouth are visible, however, and do not have eelgrass beds that appear on later photographs.

A June 1942 photograph sequence shows eelgrass widely dispersed in the bay, but the beds are small. In the East Branch, numerous circular patches 5 - 30 m in diameter are aggregated on submerged sand bars, with more continuous beds stretching along channels. Eelgrass was considerably less abundant in the West Branch during this period, and the most prominent beds grew in the north end of the bay, around Great Island, and near the mouth of the estuary, particularly north of Bailey Flat. The upper estuarine limit of eelgrass in the East Branch was 200 m north of Upper Spectacle Island, and 100 m north of Great Island in the West Branch.

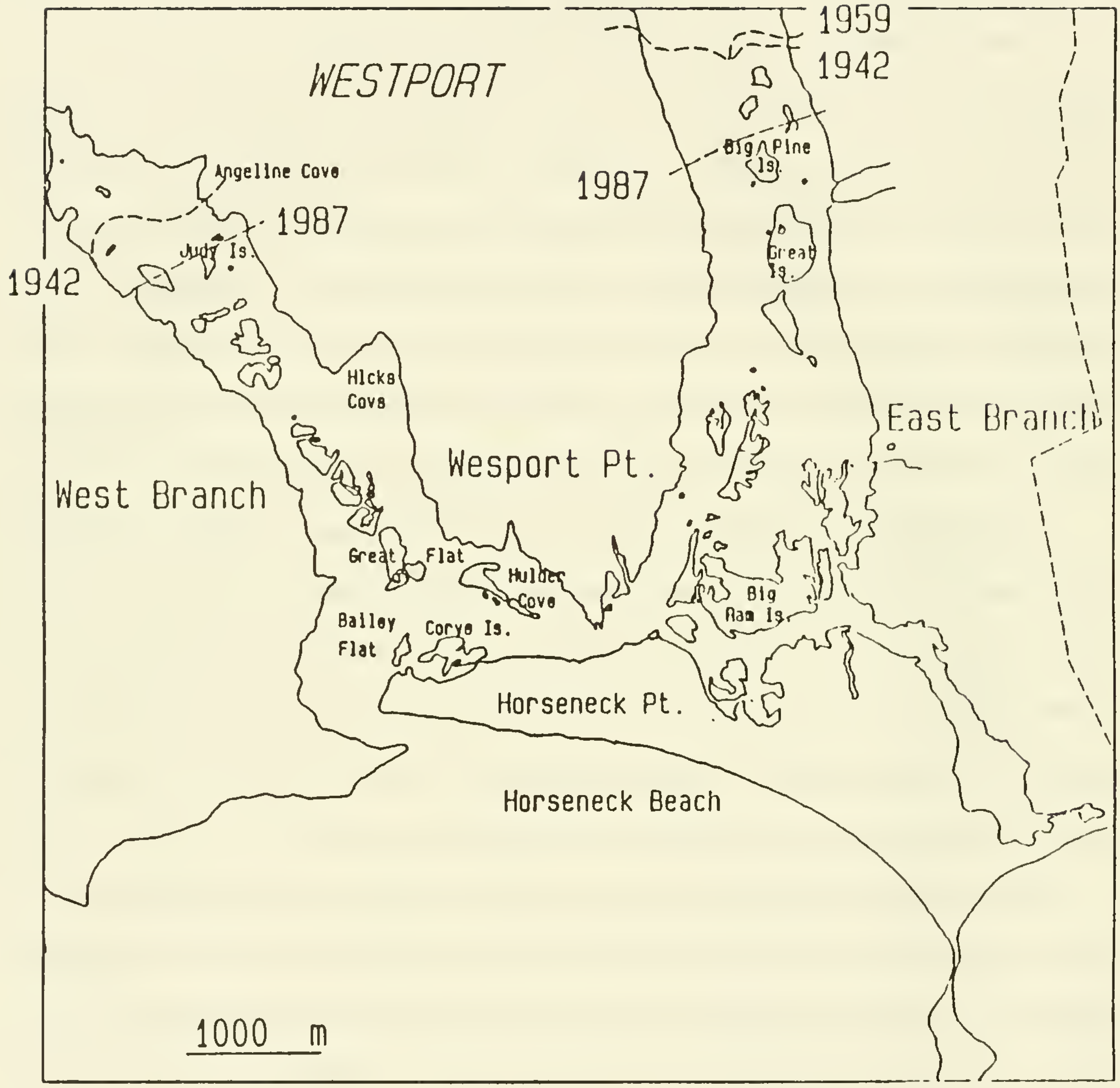

Figure 1. Site names around the Westport Rivers.

Dashed lines indicate upper extent of eelgrass in the northern part of the estuary on different dates. The position of eelgrass beds north of detail of the Westport Rivers showing site names, and changes in the upper estuary limits of eelgrass growth.

Because more freshwater enters the East Branch, the higher densities of eelgrass there are consistent with higher bed survival near streams observed elsewhere after the wasting disease Rasmussen (1977). This does not explain bed abundance near the mouth, although it is possible that these beds were recruited after the disease.

No photographs were obtained showing changes in eelgrass abundance due to the 1944 hurricane. During the 1950's, three sets of imagery are available: 22 April 1954, 1 May 56, and 22 September 1959, but none of these surveys had complete coverage of submerged features. The 1954 survey of the West Branch shows eelgrass is absent from the north end of that river, but abundant near the mouth of the estuary. The absence of eelgrass near in the upper part of the River is due to the fact that even today, many of these beds in shallow water are annual, and do not appear until after June.

Like the 1954 imagery, 1956 photographs show eelgrass nearly absent in the upper West Branch, but eelgrass is diminished near the mouth as well. In particular, beds around Whites Flat and Bailey Flat are substantially reduced, even though this photograph series was taken later in the growing season. The cause of this decline appears to be do to the September 1954 hurricane, and there are several changes in bathymetry near the mouth such as shoal movement around Bailey Flat, and enlargement of a channel across Whites Flat.

The September 1959 survey included only the upper East Branch, but eelgrass is more abundant than summer 1942, and occurs as large continuous beds. The northern limit of growth has extended 100 m

further north, and a 9.5 ha bed grows across the channel north of Little Spectacle Island.

A 10 April 1962 series of photographs are remarkable in that eelgrass is nearly absent from all parts of the bay, including the deep perennial beds that are visible on the early spring 1954 and 1956 photographs. The only perennial vegetation near the mouth are beds along the deepest parts of the main channel walls. Some small patches occur in shallow water around the bay, and the largest of these were several <0.5 ha beds around Great Island in the West Branch. The likely cause of this decline was the September 1960 hurricane, and ice scouring and a blizzard in 1961. These storms also caused shoal movement near the mouth, and further enlarged the channel across Whites Flat.

A September 1969 image has too much cloud cover to observe fine detail, but eelgrass is abundant north of Bailey Flat and appears to extend in the West Branch to Judy Island and in the East of Great Island. In November 1979, eelgrass distribution is abundant in the main channel at the bottom of the east branch, and some patches extend north at least to Sanford Flat in the West branch and Great Island in the East Branch. Vegetation is sparse in both Branches, but this could be due to severe ice scour in 1977, and a blizzard with exceptional tides and winds in 1978. A June 1982 photograph of the West Branch shows that eelgrass remains sparse throughout the upper limits of the estuary, even though there was no recent disturbance. Since 1985, eelgrass has expanded greatly in the lower end of each Branch of the Westport River, but has not extended further north into the estuary.

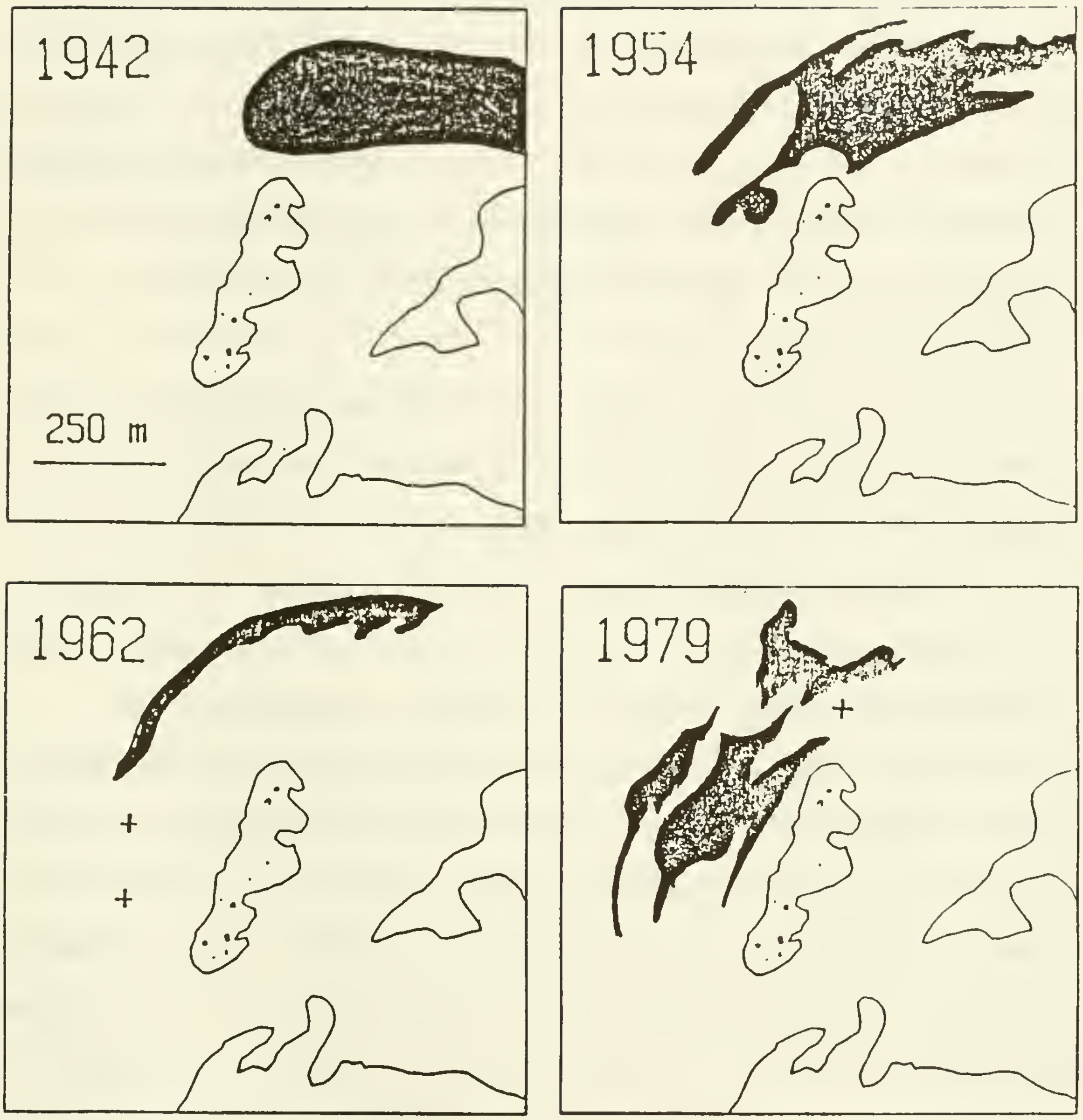

Figure 2. Changes in eelgrass bed position and flat migration north of Bailey Flat, Westport.

Darkened areas indicate where eelgrass is present.

Overall, the Westport River has the most complex history of changing eelgrass abundance of any site studied in Buzzards Bay. The shallow bathymetry in this estuary make eelgrass populations susceptible to storms and ice scour, and likely accounts for the wide fluctuations in eelgrass cover observed. This pattern is markedly different from bed recolonization on the outer coast which typically show continuous expansion over decades.

Changes in bed cover around some areas like Bailey Flat (Fig. 2) can be explained by migrating shoals, storms and ice scouring. Other changes, like the migrating upper estuarine limit of eelgrass growth (Fig. 1), and the general decline in eelgrass abundance in the upper part of the estuary since the 1940's and 1950's are likely due to other causes such as nutrient loading. For example, benthic algae and eelgrass algal epiphytes become more conspicuous as one moves northward into the West Branch. Near the mouth, the depth of eelgrass growth is 2.5 m whereas east of Sanford Flat, eelgrass grows to less than 0.5 meters. Shellfish beds in the north end of the East Branch have been closed due to high fecal coliform counts, and elsewhere bacterial inputs are usually associated with nutrient inputs. Together, these facts suggest that nutrient loading is becoming problematic in the Westport Rivers, and needs further study.

Given the importance of this estuary, a more comprehensive understanding of the changing eelgrass abundance there is desirable. Periodic photographic surveys should be taken under favorable conditions during several growing seasons, and damage from storms and ice scouring should be monitored. Historical changes in distribution and abundance

can be accurately documented from sediment cores taken at suitable locations around the bay.

Apponaganset Bay, Dartmouth

Like the Westport Rivers, Apponagansett Bay, in South Dartmouth is a shallow embayment with abundant shellfish beds. There is considerably less freshwater input here than in the Westport Rivers, and the main surface input is from Buttonwood Brook (Fig.3), which includes animal waste from the New Bedford Zoo. The salinity of virtually all of the bay is above 20 ppt (J. Freitas, pers. communication). Padanaram on the eastern shore is densely developed, and residences are serviced by septic tanks.

A sediment core taken 150 m west of Little Island (see chapter 3) and other historical documentation was suggest that eelgrass was abundant in the inner Bay for many years prior to the decline of the wasting disease. Afterwards. eelgrass began to recover with some major fluctuation during 1940-1960, but declined again in the last 15 years. In contrast, eelgrass in the outer Bay continuously expanded after onset of colonization in the 1940's.

The cause of these changes can be inferred from the long-term patterns of eelgrass distribution in this Bay, and the time when changes occurred. For example, coastal charts of Apponagansett Bay from the turn of the century shows that eelgrass is abundant in the deeper part of the inner harbor (0.9-1.8 m MLW; Fig. 4a). Typical of these charts, eelgrass is occasionally noted where it is abundant, but to avoid clutter eelgrass is not identified in all areas where it grows. This

fact is demonstrated by the core data, because eelgrass was continuously abundant west of Great Island prior to the wasting disease, but is not indicated there on these early charts. If recent photographs can be used as a guide to determine the nearshore and northern limits of growth, it would appear that all but the deepest parts of the Bay was filled with eelgrass early in this century (Fig. 4b).

A 12 December 1938 is difficult to interpret because of unsuitable field conditions and poor imagery, and virtually no eelgrass is visible. No eelgrass grew around Marshy Pt. or south to Ricketsons Pt. The bottom of the inner harbor appears uniform and free of eelgrass which could be the result of the September 1938 hurricane, or image quality.

In contrast, a winter 1941 photograph shows eelgrass abundant throughout the bay (Fig.4c). This photograph is remarkable because eelgrass is dense and continuous, even though much of the western and northern ends of the Bay are iced over, and obscures the full extent of eelgrass cover. At this time eelgrass began to colonize near Giffords Boat Yard and between Marshy Point and Ricketsons Point, as well as among the boulder field east of Ricketsons Pt. A photograph taken June, 1942 has too much water turbidity for interpretation, but parts of some 1941 beds are visible.

A September 1951 image shows that eelgrass is widespread, but is largely confined to the margins of the harbor, and no patches occur in water great than 1.0 m MLW (Fig. 4d). Outside the bay, however, eelgrass is expanding and becoming more dense around Marshy Point and south to Ricketsons Point. Some patches are present on the west side of

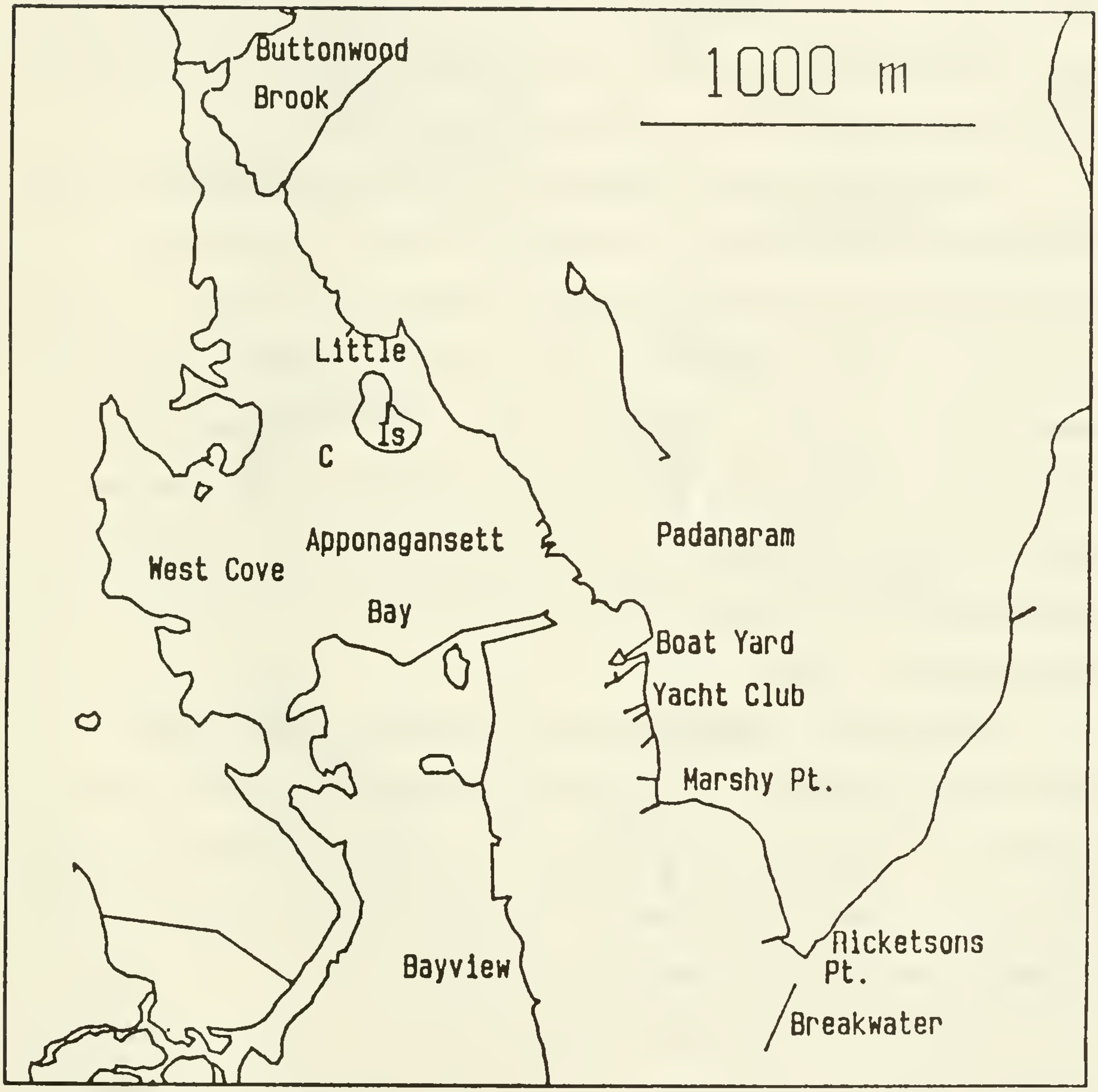

Figure 3. Map showing site names around Apponagansett Bay, So. Dartmouth.

The location of a sediment core is labeled 'C'.

the outer bay as well. Because there were no major disturbances for several years prior to this photograph, these trends suggest declining water transparency in the inner bay was the likely cause for the absence of eelgrass there, rather than disease or ice scour.

A summer 1959 image of the northern fifth of the bay shows a large diffuse patch of eelgrass north of Little Island. An April 1962 photograph shows eelgrass widespread throughout the bay (Fig. 4e), but the beds are sparse, possibly because the photo was taken early in the growing season, or like the Westport River, these beds were greatly affected by storms and ice scour during 1960 and 1961. Nonetheless, eelgrass is more widespread, and shows a greater depth of growth than present on the 1951 imagery. Beds on the eastern shore of the outer bay appear denser as well.

Eelgrass was even more abundant in September 1966, and beds proliferated especially in the western lobe of the inner bay. The positions of many beds, but positions were again different from the 1962 distribution. Beds on the eastern shore of the outer Bay were the more extensive than any time since 1938.

A October 1971 photograph lacks detail, but eelgrass appears abundant south of Great Island. In 1975, dense vegetation is present in several patches around the bay, but by October 1981, most eelgrass is absent from the inner bay. Some vegetation appears along the banks at the head of the Bay in the 1981 photograph, but it was assumed to be largely composed of drift algae or Ruppia.

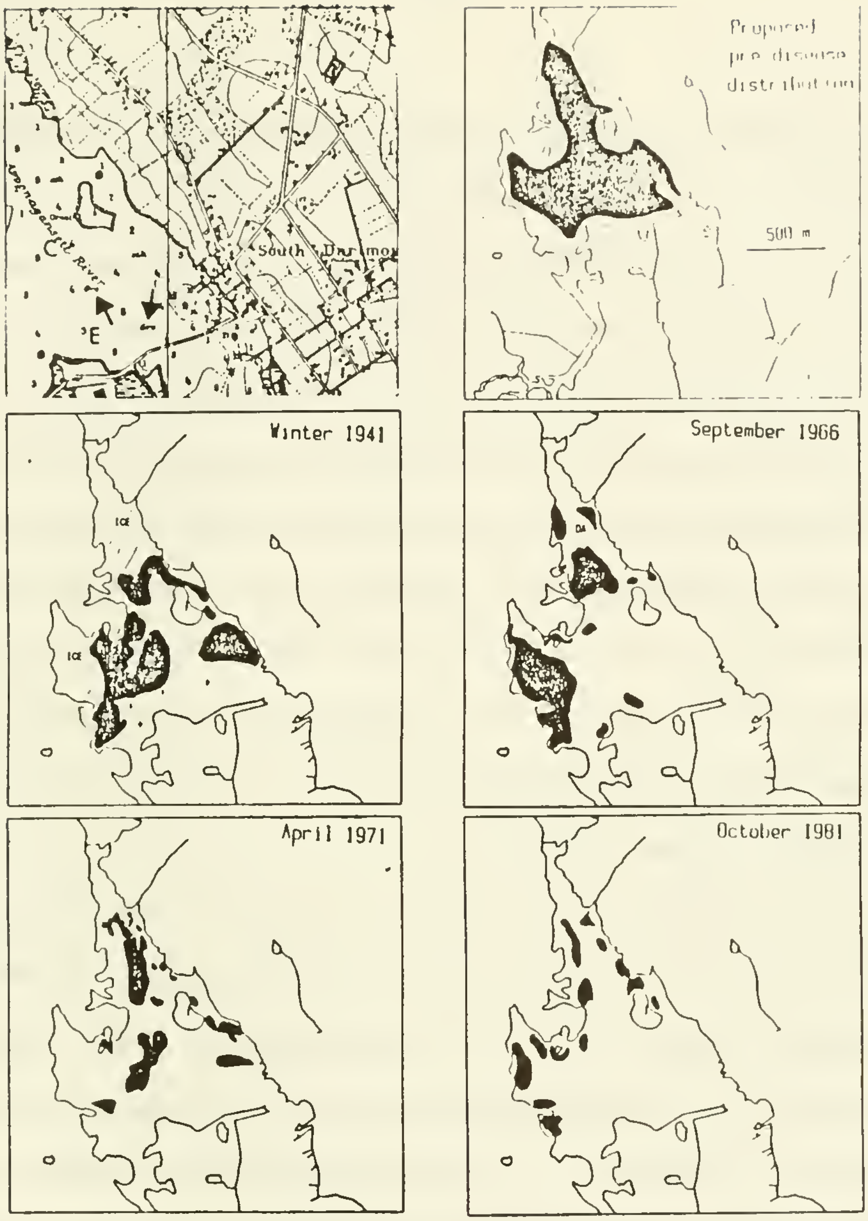

Figure 4. Eelgrass in Apponagansett Bay, So. Dartmouth during 6 periods.

Top left, a USCGS nautical chart ca. 1890 indicating the presence of eelgrass (arrows). Also indicated are denotation of eelgrass on another nautical chart (E), and location of sediment core (C) showing long-term presence of eelgrass. Top right, likely pre-wasting disease distribution, based on charts, core data, and anecdotes. Other maps from photographs, solid areas indicate eelgrass beds of any % cover. No eelgrass was found during a field survey in 1985.

The greatest post-disease cover in the inner Bay occurred during the mid 1960's, but eelgrass never returned to its pre-wasting disease abundance. This contrasts with the outer Bay, which showed continuous expansion of eelgrass cover for decades. These observations, and the loss of eelgrass in inner Bay during the 1980's suggest there have been declines in water quality in the inner Bay. For example, the eastern shore of the inner bay has also been closed to shellfishing for several years due to high loads of fecal coliform. Sources of these coliform may include failing septic tanks, waste discharges in Buttonwood Brook, or feces from several thousand Canada geese that often feed on local agricultural land and roost along shore. Each of these sources is associated with nutrient inputs.

Nutrient loading is implicated as the cause of the recent decline because drift algae have been increasing conspicuously, and the odor of decaying algae has become a public nuisance in some areas (press reports). Large sheets of *Ulva* or clumps of *Gracillaria* cover the bottom of parts of the Bay. Some parts of the inner harbor is covered with a rich gelatinous ooze of mud and decaying algae that has been observed in other enriched embayments (e.g., Brush, 1984). The maximum depth of growth of eelgrass declines from 2.4 m MLW near the mouth to 1.2 m MLW by the marina, then disappears altogether in then inner Bay.

Boat traffic may also be contributing to decreased light availability to eelgrass because boat use has increased substantially in this bay in recent decades (Fig. 5). The inner bay has a shallow, muddy bottom, and power boats leave conspicuous plumes (pers. observ). This

activity not only resuspends sediments, but releases nutrients from pore water.

The history of pollution in Apponagansett Bay needs further study because eelgrass was less abundant in the Bay in 1951 than in the 1940's or 1960's. This loss does not appear to be do to disease because eelgrass disappeared from the deeper parts of the Bay, but persisted in shallow water. This Bay has been disturbed for many decades, and this observation suggests that water transparency decreased at that time.

Clarks Cove and New Bedford Harbor

The Clarks Cove-New Bedford Harbor-Acushnet River estuary system has undergone major physical and chemical perturbations from industrial and urban activity for more than a century. The history of discharges in this area is complex and includes sewage, dyes, PCBs, and heavy metals during different periods. Three towns (Dartmouth, New Bedford, and Fairhaven) adjoin these waters, but the largest and most toxic inputs have originated from New Bedford. In addition, a hurricane barrier was constructed during 1962-64 in New Bedford, along the northeast and northern shores of Clarks Cove, and along the eastern shore of Clarks Point to the inner harbor of New Bedford.

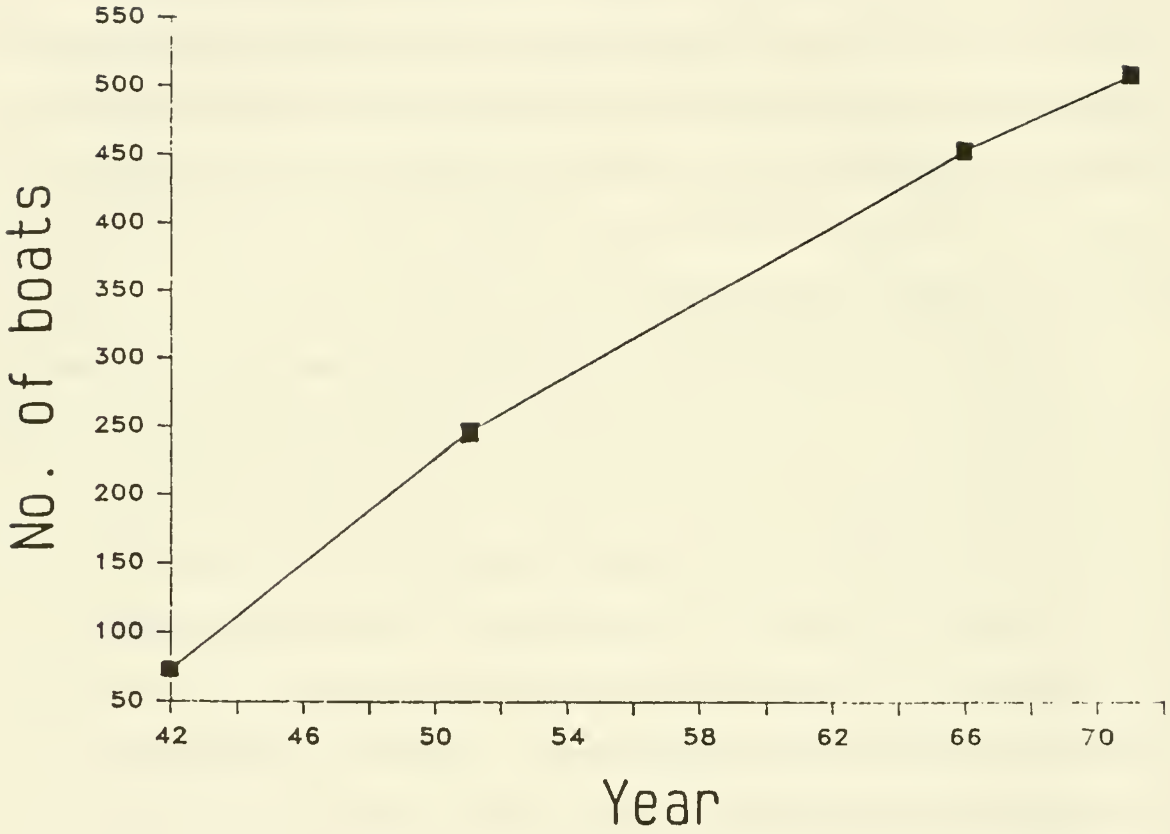

Figure 5. Boats moored or in transit in inner and outer of Apponagansett Bay on four dates during comparable times in the recreational season.

Most of New Bedford's sewage discharges at the tip of Clarks Point today. This may be an important factor affecting local water transparency because the resulting plume offshore is conspicuous on all aerial surveys obtained, and the 100-200 m wide plume is visible often stretching 1000's of m into the waters of the neighboring town. In the past, more than 170 pipes discharged along shore as well (New Bedford Town Hall Report). Prior to 1970 many of these outfalls were in use and received both industrial waste and street runoff. Others were tied in to the sewer-street drain system, and during periods of high rains, sewage was discharged diverted to them as well.

Today, no eelgrass grows in New Bedford Harbor-Acushnet River or Clarks Cove, except for a bed at the tip of Clarks Point and south of Moshers Point (Appendix I). The absence of eelgrass is not due to salinity limitations because fresh water discharge by the Acushnet River is not large. Furthermore, eelgrass grew elsewhere along the coast prior to the construction of the hurricane barriers, including around Palmers Island in the inner harbor, and around cotton mill discharge pipes at the northeast shore of Clarks Cove (B. Burke, New Bedford shellfish warden and James Costa, pers comm.). The construction of the barriers may have contributed to the loss of some eelgrass and potential eelgrass habitat because several km of beach and shallow shoals were eliminated, and tidal flushing was reduced in the inner harbor.

Ten different aerial surveys since 1944 were obtained that included this area, but it was difficult to document changes in eelgrass abundance on these photographs for several reasons. This area was urbanized prior to the wasting disease, and on the earliest photographs,

large portions of shore had been replaced by piers, revetments, and warehouses. Beach slopes are steep, and the zone where eelgrass grows is often too narrow to be interpreted from photographs. Water transparency is poor on most available photographs, especially in the inner harbor. Algae covered rock and cobble are abundant in some areas, making it difficult to delimit eelgrass bed boundaries. Finally, eelgrass never became abundant in this area after the wasting disease.

Even with these limitations, there are some areas where eelgrass is visible on aerial photographs during the 1950's or 60's, but no longer present today (Fig 6). Only in two areas (tip of Clarks Point, So of Moshers Point) did eelgrass abundance increase after 1966 (Fig. 6).

Other changes in vegetation are also visible on the photographs. For example, *Codium* is now abundant between Fort Phoenix, Little Egg Island, and Sconticut Neck, and probably accounts for the vegetation to increase in this area between 1966 and 1981 photographs. In some areas (such as south of Fort Phoenix), it is difficult to identify vegetation.

These observations are fragmentary, but eelgrass did not colonize this area appreciably after the wasting disease, and the few beds that became established were destroyed by the late 1960's. Whether the lack of recovery and new losses were the result of burial, changing hydrography, declining water quality, or buildup of toxic substances in the sediments is unclear. The absence of eelgrass over such a large area, is unique in Buzzards Bay and suggests that there have been large scale effects of human perturbations around New Bedford.

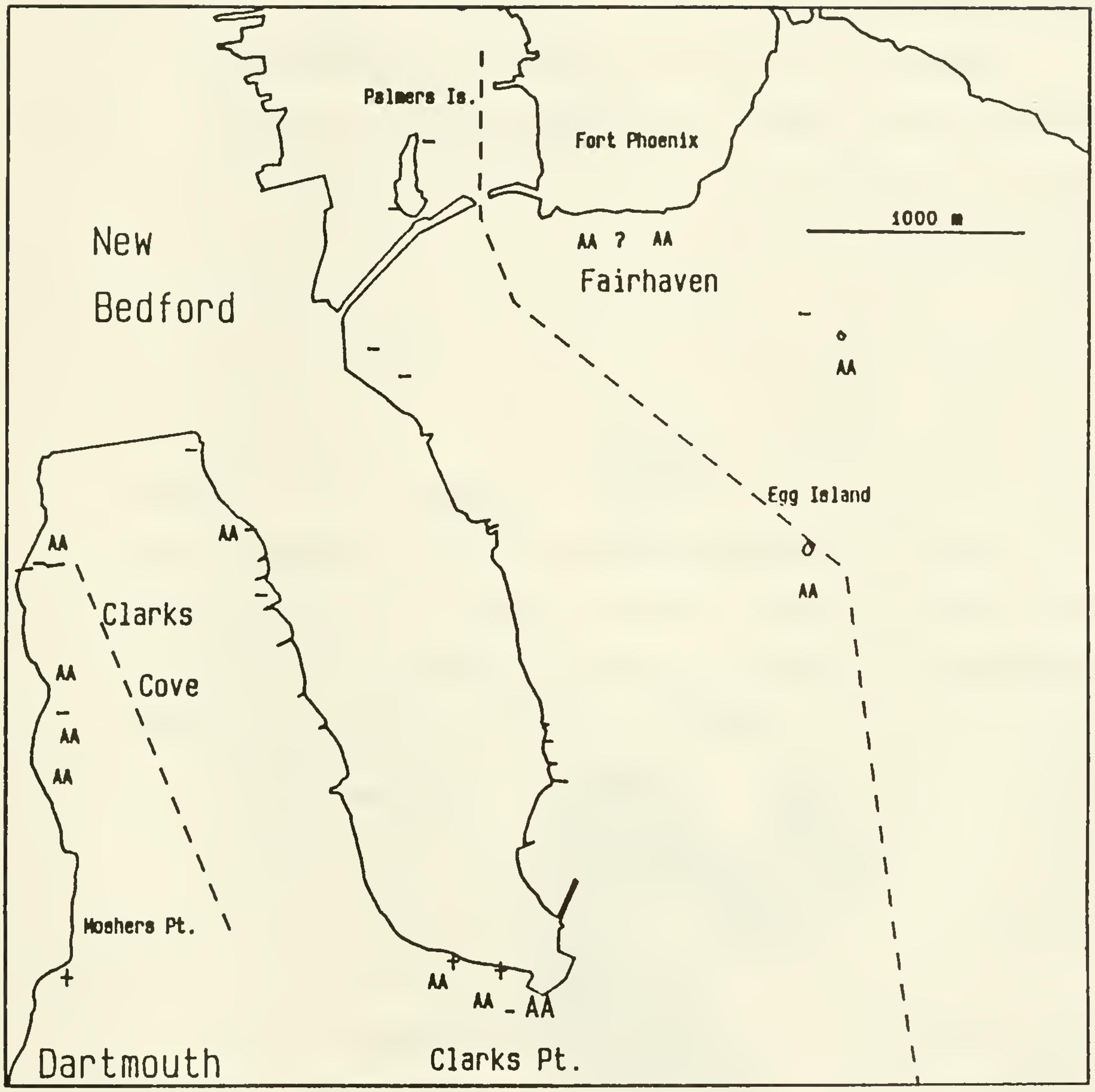

Figure 6. Dates and locations of former eelgrass populations around New Bedford based on reports and photographs.

Areas where eelgrass has declined during 1944-1981 are marked by (-); areas of increase after 1966 are marked by (+). The (?) indicates increasing vegetation of questionable identity.

Nasketucket Bay, Fairhaven

Nasketucket Bay is an enclosed area on the eastern side of Sconticut Neck. This bay is relatively protected from storms, has had little housing development along shore, and has been a productive shellfish habitat (Durso et al., 1979). The only appreciable surface flow of freshwater entering the Bay is through a network of creeks and streams entering Little Bay. This input is noteworthy because these streams drain hundreds of ha of farmland, pastures, and developed land, and Little Bay is the only area where eelgrass is absent today.

Lewis and Taylor (1933), listed areas of eelgrass decline on the east coast as a result of the wasting disease, and noted the "well-known meadows about ... Sconticut Neck in Buzzards Bay ... [which] were nearly or quite depopulated." The recolonization of eelgrass after the disease was documented with 8 aerial surveys taken between 1951 and 1981. A town shellfish report (Durso et al., 1979) and field observations in 1985 were used to document recent distribution.

The changes in eelgrass abundance here are typical of deeper, well flushed embayments in Buzzards Bay: slow and nearly steady recolonization over 30 years, without the wide swings in abundance seen in shallow estuaries like the Westport Rivers. Most expansion occurred during the late 1950's to early 1960's.

The earliest photographs (1951 and 1956) show that many populations of eelgrass are scattered around Nasketucket and Little Bays (Fig. 7). Some populations occurred up to 2 km offshore suggesting that

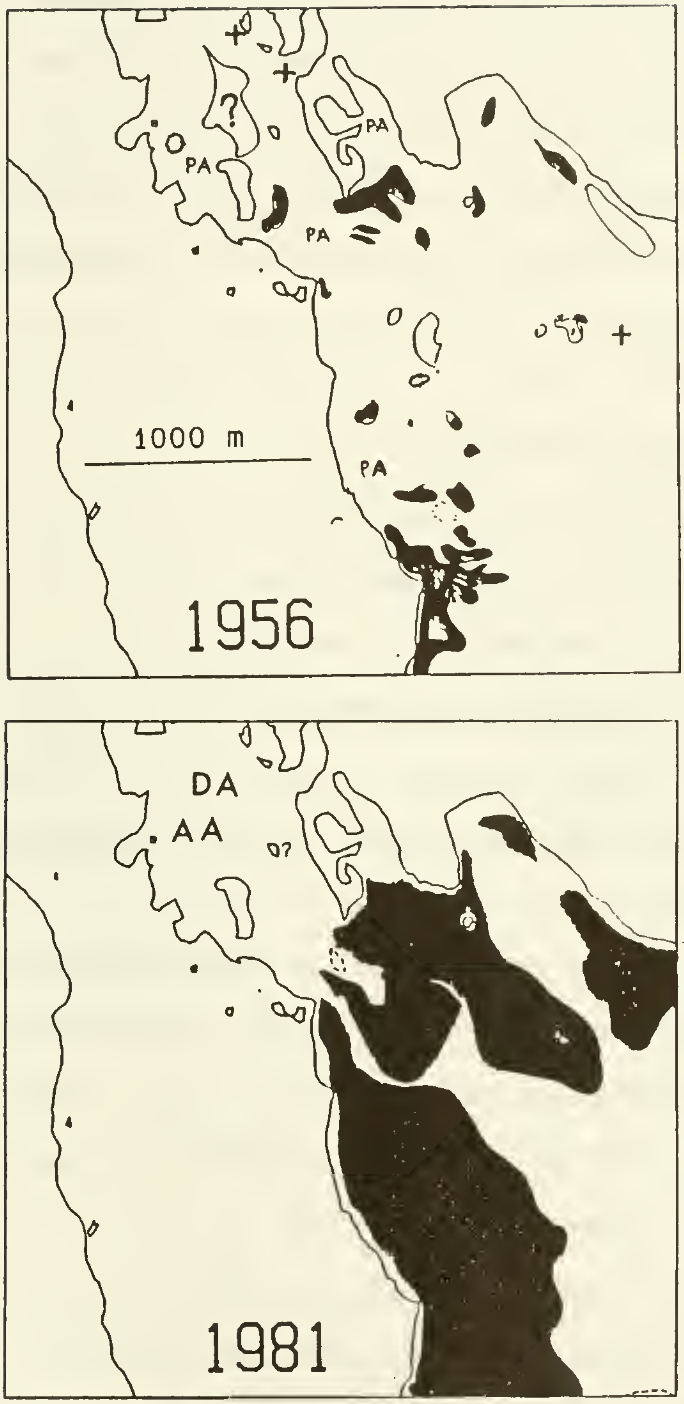

Figure 7. Eelgrass distribution in Nasketucket Bay during 1956 and 1981. Solid beds have greater than 50% cover.

refuge populations in deeper water survived the disease. The loss of eelgrass in Little Bay may be due to enrichment because drift algae and periphyton are very abundant there today. Photographs of Little Bay from the 1950's and early 1960's shows a light colored, sandy mud bottom, later photographs show a darker bottom suggesting an increase of organic matter or silt.

East Bay, West Island, Fairhaven

Like Nasketucket Bay, East Bay is a good example of an isolated, relatively undisturbed, well flushed coastal area. Unlike the former, it is very shallow, and exposed to moderate wave scour. This bay, like other undisturbed areas on the outer coast show continuous expansion for decades after the wasting disease. Because of local hydrography, wave scour, and longshore sand transport, eelgrass beds growing here have a "banded" or granular appearance.

Early records or descriptions of eelgrass abundance are not available for East Cove. Lewis and Taylor (1933) state that eelgrass was abundant on Sconticut Neck prior to the wasting disease. It is likely eelgrass also grew along West Island because eelgrass is equally abundant in both areas today.

The beds that colonized the shallow areas of East Bay were derived from deep beds offshore the rocky island mid-bay (Fig. 8). The process of colonization here was similar to other moderate to high energy coasts: new, discrete patches of vegetation appeared on bare areas during the 1950's and 1960' and available habitat was saturated by a combination of vegetative growth and recruitment of new beds. The

hurricane in 1954 destroyed some shallow beds that were established by 1951 (Fig. 8). This disturbance resulted in slower eelgrass expansion, rather than decline, when total eelgrass cover is examined (Fig. 9, top), because eelgrass cover expanded in deeper areas during the photograph sequence that included this storm.

By 1971, most of East Bay was colonized with eelgrass, including very shallow stations nearshore (Fig. 8 and 9, top) . The decline in early 1971 (Fig. 9) is an artifact because this datum is based on a photograph taken in early spring, while the data surrounding it are from Fall surveys. Because the beds in the shallowest parts of the cove are mostly annual populations, they are not always apparent in early spring photographs. The decline in 1981, however, is based on Fall imagery, and probably due to storms and ice scouring in the late 1970's. Declines during this period occurred elsewhere in Buzzards Bay as well (see Great Neck, Wareham description below).

The west shore of East Bay has been conspicuously eroding, and the width of vegetated land between the beach and a salt marsh drainage channel was measured on eight positions on different dates. Erosion rate was higher prior to eelgrass colonization than after (Fig. 9). This may not be due to solely to the damping or baffling effects of eelgrass offshore since hurricanes in 1954 and 1960 probably account for the higher rates observed during those periods. Eelgrass must play a role, however, since the Blizzard of 1978, a powerful northeaster that eroded other areas (Aubrey and Speer, 1984; Zeeb, 1985), did not result in appreciably higher erosion rates here.

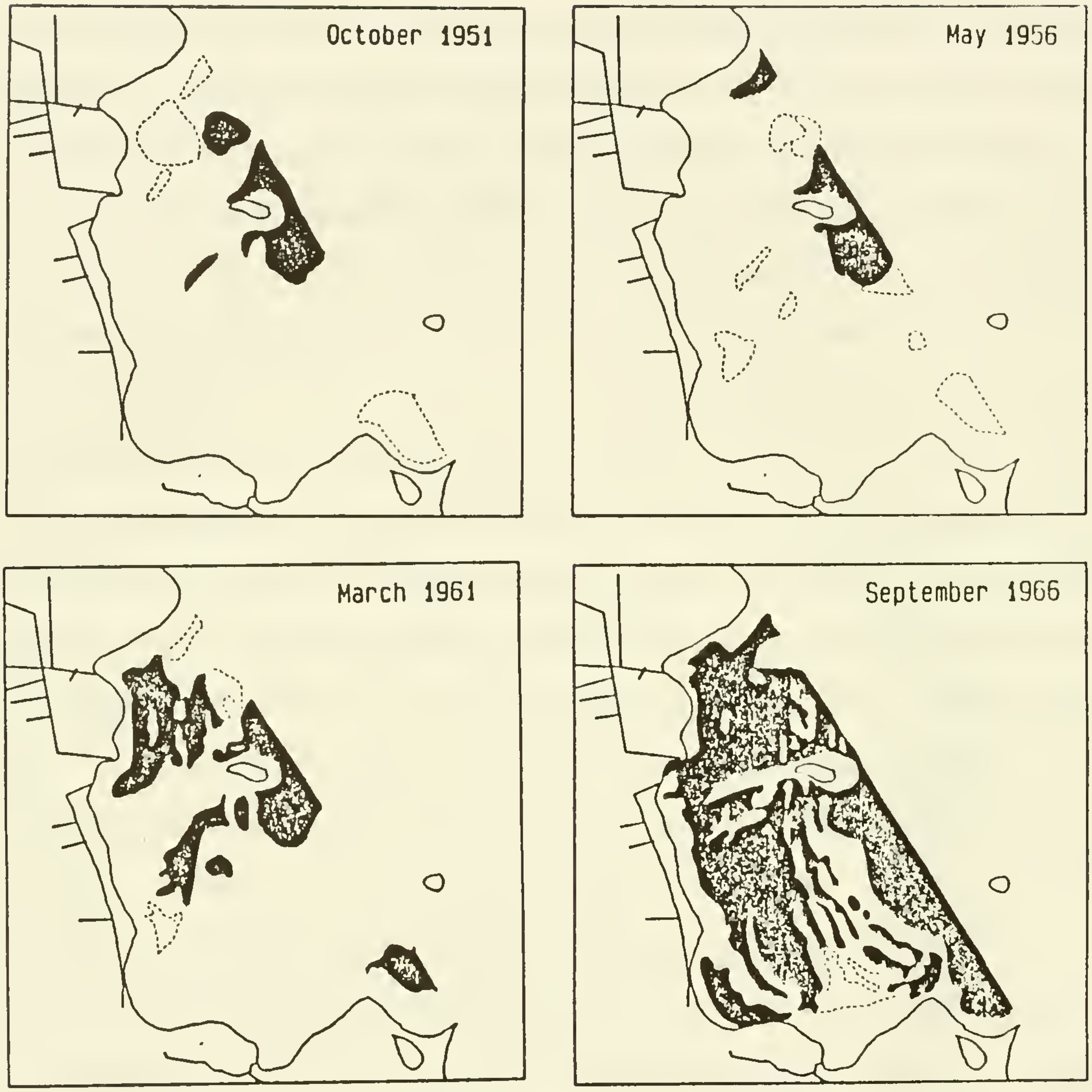

Figure 8. Eelgrass distribution in East Cove of West Island, Fairhaven during four different periods.

The lines cutting into the western shore are a network of salt marsh drainage ditches that were used as reference points to measure beach erosion. Beds covering more than 50% of the bottom are solid, open beds have less than 50% cover. Total eelgrass cover for these and other date are shown in Fig. 9.

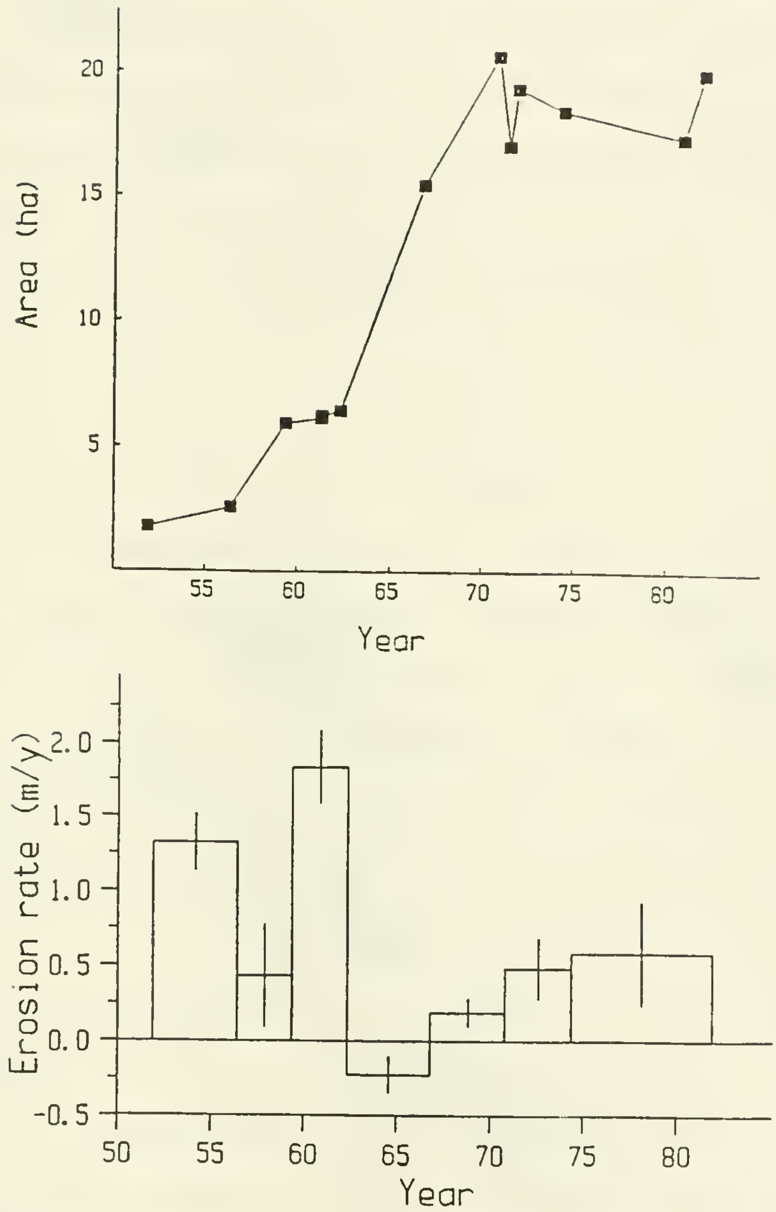

Figure 9. Recent changes in eelgrass cover and beach erosion on West Island.

Top: eelgrass area (corrected for percent cover) in East Bay 1951-1981. Bottom: Mean erosion rates at eight stations along shore (+/- SE), during the same period.

Sippican Harbor, Marion

Sippican Harbor is surrounded by rural and suburban house densities as well as some agricultural land. This town has long been a resort community, but in recent years small craft traffic has increased appreciably (G.Taft, pers. comm.). Many good shellfish areas exist here, and oyster reefs were denoted at the mouth of Briggs Cove on charts prior to the 1930.

Photographs taken June 1930 of upper Sippican Harbor (Marion town Hall vault) were the only photographs taken prior to the wasting disease discovered for any part of Buzzards Bay. These photographs are oblique, but eelgrass could be mapped (Fig. 10). Remarkably, the present day distribution of eelgrass in 1981 is almost identical to the 1930 distribution. The one exception is that eelgrass is slightly less abundant today in the innermost parts of the harbor. These photographs suggest that eelgrass peak abundance today (except in disturbed areas) is indicative of distribution prior to the disease.

Eelgrass showed the greatest rates of expansion during the 1950's and 1960's (Fig. 10). The large decline apparent on the 1971 aerial survey is enigmatic, but may be the result of sewage discharges. Declines in eelgrass abundance in some areas in the upper reaches of the Sippican River, Briggs Cove, and Planting Island Cove may be related to declining water quality. For example, throughout this area there has been increased development, boat traffic, and shellfish bed closures in recent years. The warden noticed that periphyton and drift algae has become abundant in areas, such as Planting Island Cove (G. Taft, pers. comm.).

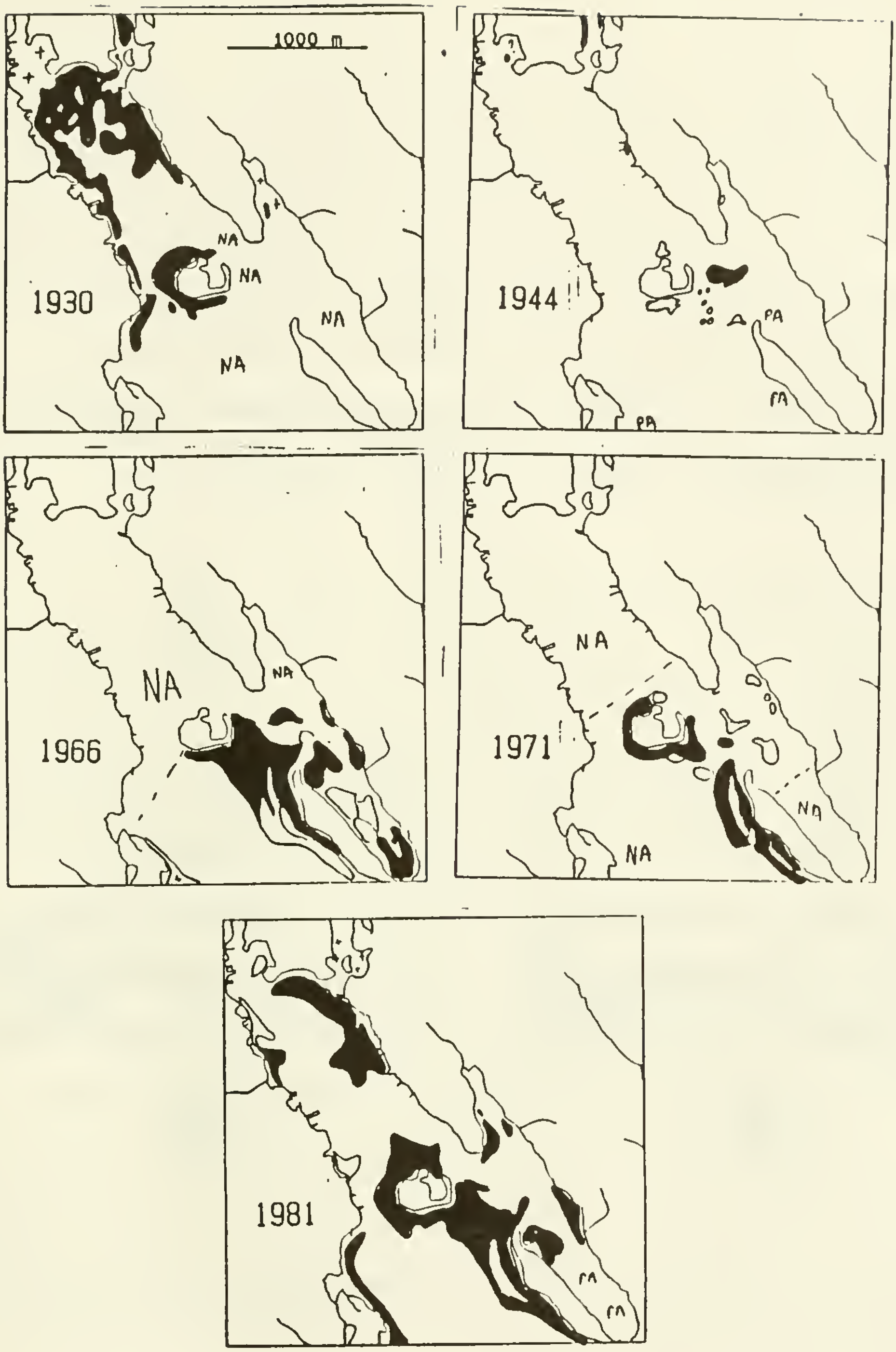

Figure 10. Historical changes in eelgrass cover in Sippican Harbor, Marion during six periods. Solid beds have at least 50% cover.

were tied to a new sewer system that emptied into a neighboring bay. This may have led to water quality improvements, and new expansion of eelgrass by 1981. This explanation seems more plausible that declines due to disease, because most of the losses occurred at the deeper margins of beds, which suggests declining light availability, and because beds closer to the mouth of the Bay expanded or remained static during the same period.

Great Neck, Wareham and the Wareham River Estuary

The waters off Great Neck are moderately well flushed, in part due to water exchange in the Cape Cod Canal, and the shoreline somewhat exposed. A shallow shelf less than 4 m MLW covers more than 800 ha offshore. Today eelgrass is extensive on these shallows.

The earliest photographs obtained (a 1956 aerial survey and fragmentary coverage from 1944 and 1951) show that eelgrass was absent from most areas, except for a large and conspicuous bed around Little Bird Island (Fig. 11). Because this bed is isolated, and little eelgrass is present onshore at this time, this population may have survived the wasting disease. These beds colonized the western lobe of Great Neck during the early fifties, then migrated eastward along Great Neck between 1955 and 1960 (Fig. 11).

The onset of colonization south of Long Beach occurred at least 10 years earlier than colonization on the shoal south of Indian Neck, 1.5 km to the east, where the first beds appeared in 1958 (Fig. 12). These beds expanded greatly, and by 1966, the population had nearly reached peak cover.

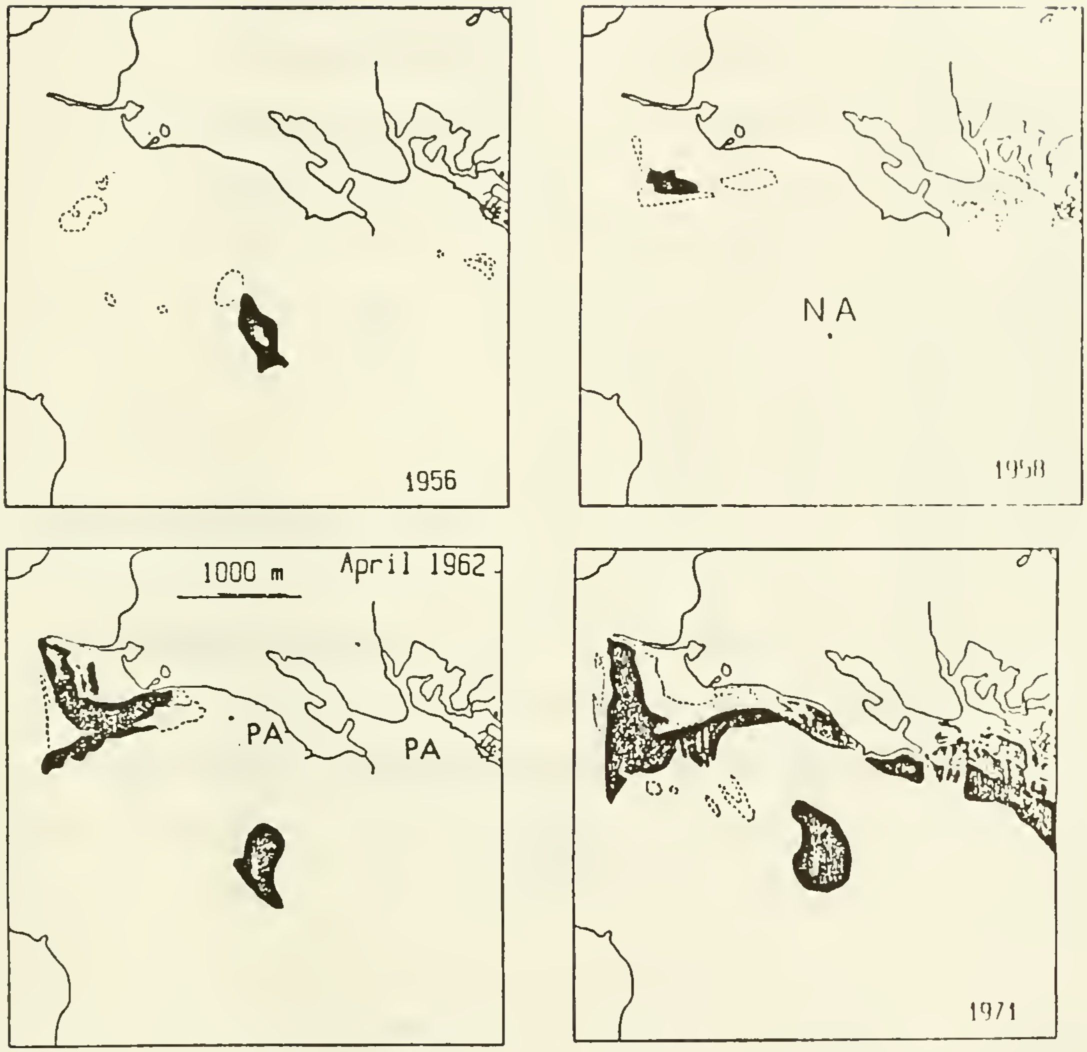

Figure 11. The pattern of eelgrass recolonization along Great Neck during four decades. Solid beds have greater than 50% cover.

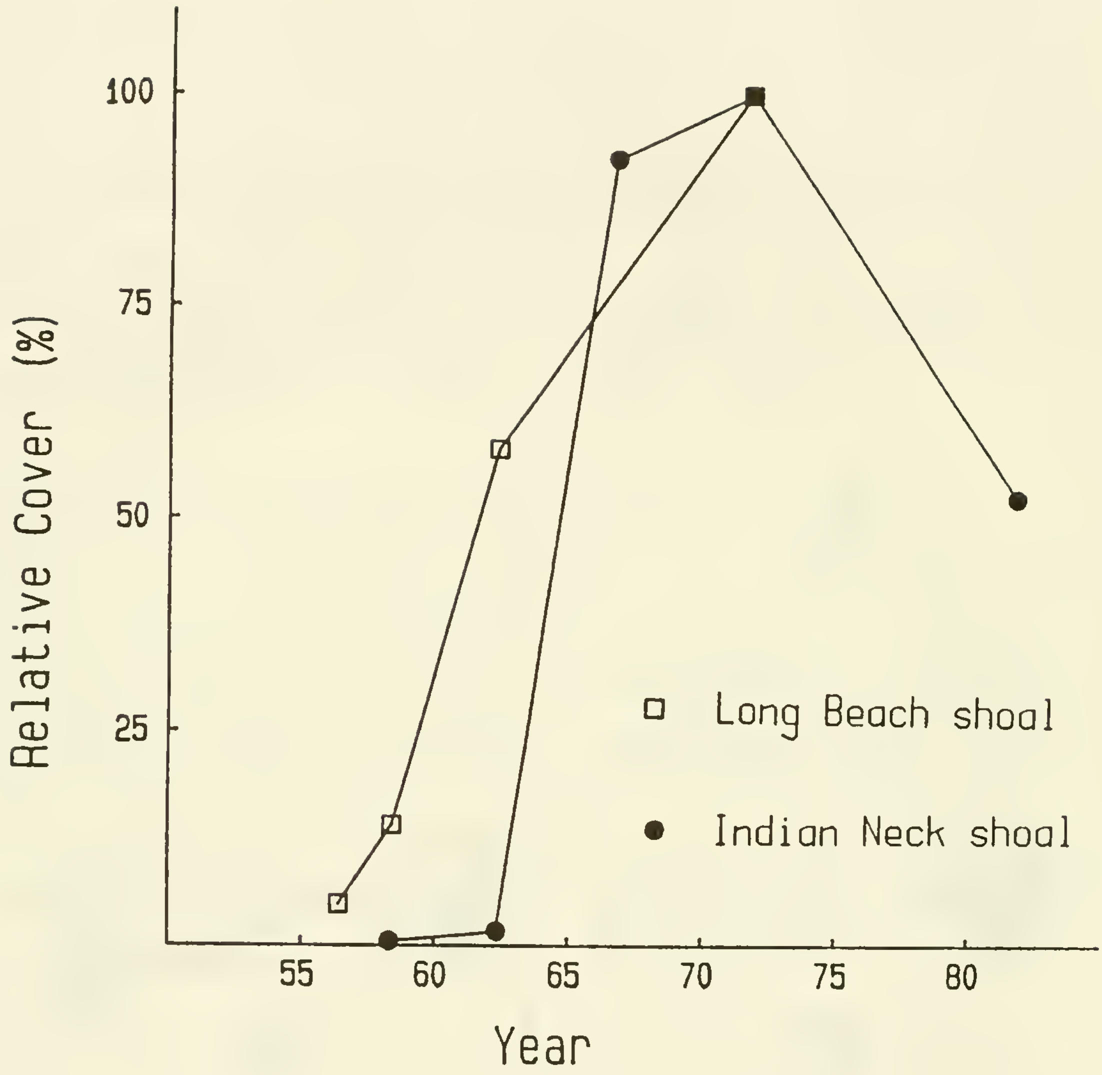

Figure 12. Recolonization of eelgrass on two areas on Great Neck, Wareham.

Data are bed cover (corrected for % cover) for the shoals south of Long Point Beach and Indian Neck. Relative cover 100 = 49.5 ha for Long Point Beach and 3.22 ha for Indian Neck.

Buttermilk Bay, Bourne and Wareham

Buttermilk Bay is a protected embayment at the north end of Buzzards Bay, with an area of 200 ha, and a 1 m MLW mean depth. In recent years, Buttermilk Bay has become polluted from development in the surrounding watershed, and the Bay is now closed to shellfishing each summer. Nutrient loading in the bay is high (Valiela and Costa, in press), but effects are localized because the tidal range is 1 m, and 50% of the water is flushed with each tide (Costa, 1988). The Cape Cod Canal (built ~1910) discharges less enriched water from Cape Cod Bay into Buzzards Bay, 1 km from the mouth of Buttermilk Bay. This additional flushing may be keeping pollution levels in Buttermilk Bay from being worse than they are.

Buttermilk Bay is the only site in Buzzards Bay where colonization of eelgrass was mapped after the wasting disease (Stevens 1935, 1936, Stevens et al., 1950). Recently, Buttermilk Bay has been studied to measure hydrography, nutrient loading, eelgrass abundance, and groundwater movement (Valiela and Costa, in press; Fish, in prep; Moog, 1987) that shed light on Stevens observations.

Stevens noted that eelgrass survived or first appeared near Red Brook, and his observations were one of many that demonstrated eelgrass beds near fresh water inputs were refuge populations from the disease. He also noted that eelgrass first appeared in Little Buttermilk Bay along its most northern shore where no streams entered. It is apparent now that this area has large groundwater inputs (pers. obser., Moog,

1987), further supporting the premise that plants near freshwater inputs better survived the disease or were the first to recover.

Analysis of eelgrass bed survival and recovery near streams after the wasting disease focused on salinity (e.g. Rasmussen, 1977). Water temperature is cooler by several degrees near Red Brook, where Stevens observed the first beds. Furthermore, groundwater springs near some areas recolonized in Little Buttermilk, locally cool seawater and sediments (pers. obs). The possible role of cooler temperature as providing a refuge from the disease is addressed in the discussion.

Stevens did not map abundance prior to the wasting disease, but he described eelgrass cover in Buttermilk and Little Buttermilk Bays as "notably abundant for many years and was almost completely destroyed between September, 1931 and September, 1932." Stevens descriptions, a 1916 Eldridge nautical chart, and sediment cores taken 60 m east of Red Brook, all suggest that eelgrass was abundant in Buttermilk Bay prior the wasting disease. The earliest photographs (June 1943) are of poor quality for vegetation analysis, but eelgrass is not as abundant in the Bay as today.

Eelgrass greatly expanded in the Bay during the 1940's, and this expansion may have been facilitated by seed production from beds outside the Bay (Stevens et al., 1950). By 1951, eelgrass had virtually filled the central portion of Buttermilk Bay (Fig. 13)., but grew only in a few areas of Little Buttermilk Bay. During the 1960's, eelgrass began to extensively colonize Little Buttermilk Bay, and grew deeper in Buttermilk Bay than during any other recent period (Fig. 14, 15 bottom). Total eelgrass cover in the central part of Buttermilk Bay in 1966 was

unchanged from the 1950's (Fig. 15 top) because of losses due to dredging and new declines in poorly flushed coves. For example, eelgrass was present in Hideaway Village Cove during the 1950's, but largely disappeared by 1966. Today no eelgrass grows along the inner shore of this cove. Eelgrass continued to decline in the deepest parts of the Bay during the 1970's and 1980's (Fig 15, bottom) but greatly expanded in Little Buttermilk Bay and other shallow areas.

The losses of eelgrass in the deep portions of the Bay and in some poorly flushed coves appear related to nutrient loading or increased turbidity. Today, eelgrass is absent from areas with the highest nutrients concentrations, depth of growth in Buttermilk Bay correlates with dissolved inorganic nitrogen content of seawater (Costa, 1988).

Overall, Buttermilk Bay has not experienced the large declines observed in other highly developed bays. This is probably due to the high flushing rate, and because the Bay is so shallow, most beds are not at the lower depth limit of growth. The loss of some vegetation since the 1960's, however, suggests that Buttermilk Bay may be affected by future increases in nutrient loading and sediment resuspension.

South of Buttermilk Bay, a 1 km wide tidal delta has been formed at the entrance of the Cape Cod Canal. This delta has been migrating southward at rates as high as 9 to 18 m y^{-1}. This feature is interesting because a large eelgrass bed grows on the south edge of the

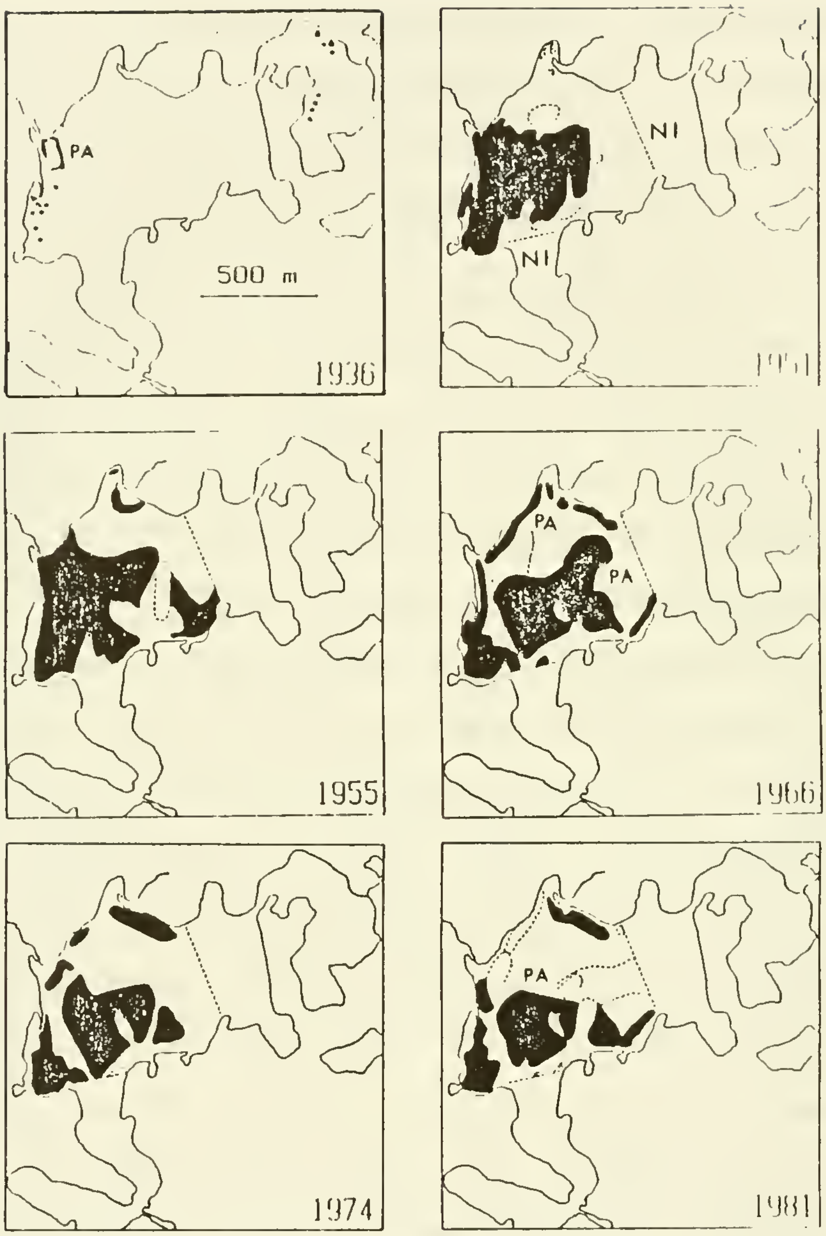

Figure 13. Eelgrass in Buttermilk Bay during various periods. Only areas included within dashed lines were analyzed for changes in area, a description of other areas is in the text. The 1935 map was based on the maps of Stevens (1936); the rectangular area denotes a region containing several beds. The "M"-shaped feature and new channels were dredged after 1955. Solid beds have greter than 50% cover.

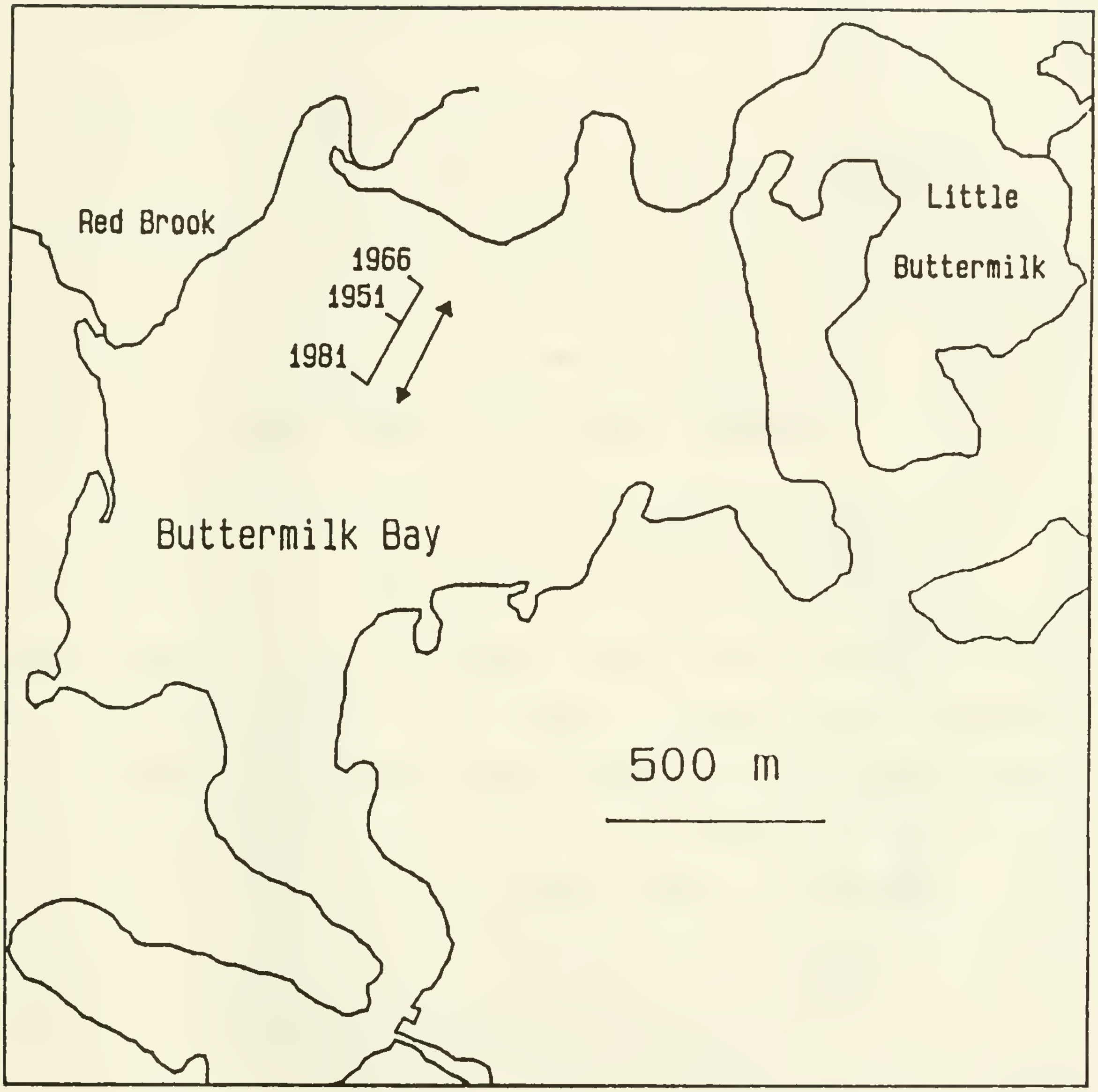

Figure 14. Relative migration (↕) of a bed boundary in central Buttermilk Bay.

The central part of the Buttermilk Bay is very shallow, therefore progression of the bed to the northeast (north at top) indicates growth in deeper water. Compare to Fig. 15, bottom.

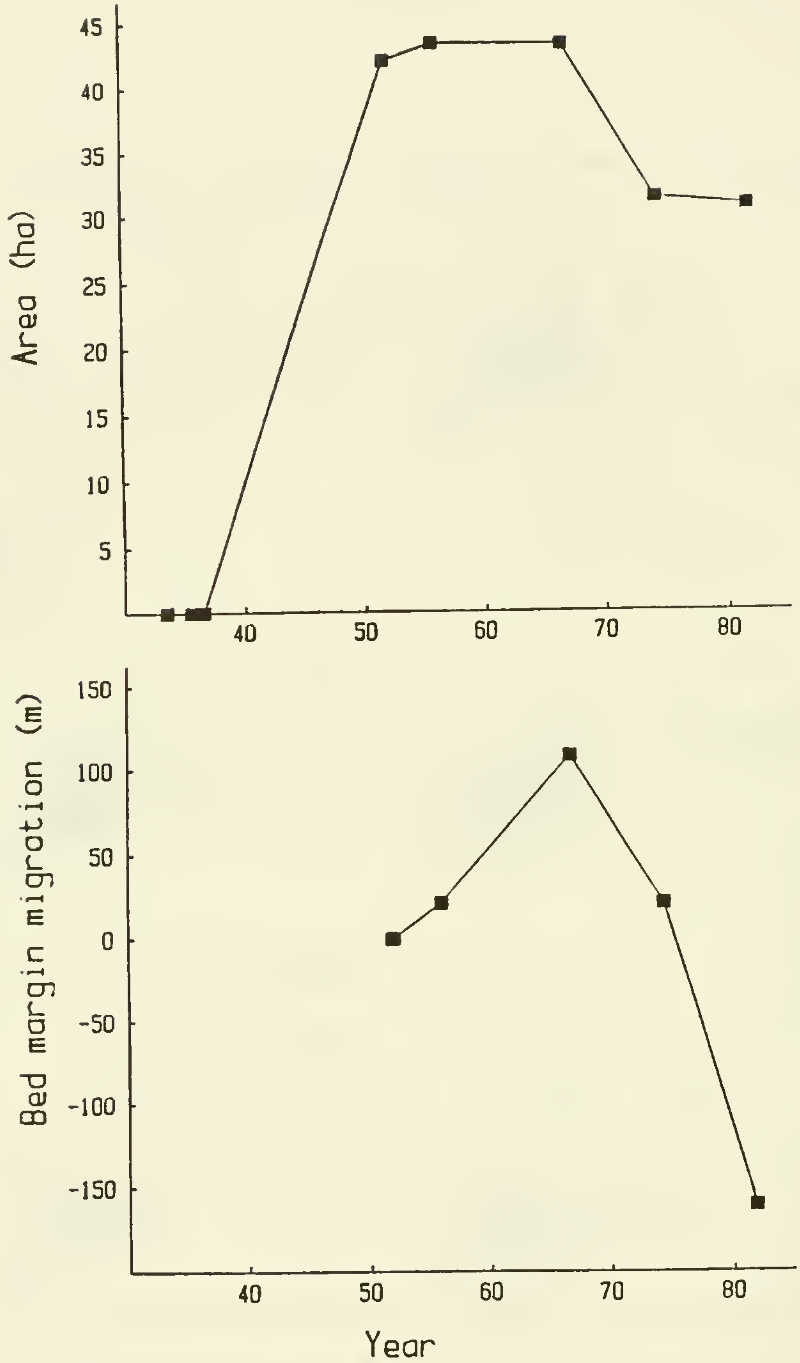

Figure 15. Eelgrass bed area (corrected for percent cover) in Buttermilk Bay (top) and position of central bed margin (bottom).

Positive bed positions represent growth in deeper water relative to 1951, negative values represent growth in shallow water. The net depth difference between the extreme positions (based on nautical charts) is between 0.3 and 0.6 m

begun to migrate southward at rates as high as 36 to 72 m y^{-1}, and has met the eelgrass bed on the south side in places.

Megansett Harbor, Bourne and Falmouth

Megansett Harbor is a moderate to high energy, well-flushed environment with a sandy bottom covered with sand waves. Most of the bay is less than 4.5 m, and today eelgrass is abundant throughout. Many beds here have a banded appearance because they grow in the troughs of sand waves or have large bare areas within them because of wave scour and storm action.

Prior to the wasting disease, eelgrass was probably equally abundant in Maganset Harbor as today, because there are numerous denotations of eelgrass alongshore on nautical charts from the 1800's. Colonization began first in the north end of the bay where a large bed on the southeast corner of Scraggy Island may have survived the disease. This bed expanded greatly and new areas were vegetated during the 1940's and 50's (Fig. 16). Bed cover remained constant in this area for 2 decades, but increased in the 1980's because of eelgrass colonization in some of the deepest parts of the Harbor.

Eelgrass colonization in the south side of Meganset Harbor lagged behind the north side, and the most rapid expansion occurred there during the 1950's.

Wild Harbor, Falmouth

Wild Harbor, is an exposed well-flushed southwest facing harbor fringed with marshes, and covered with a sandy bottom. The surrounding

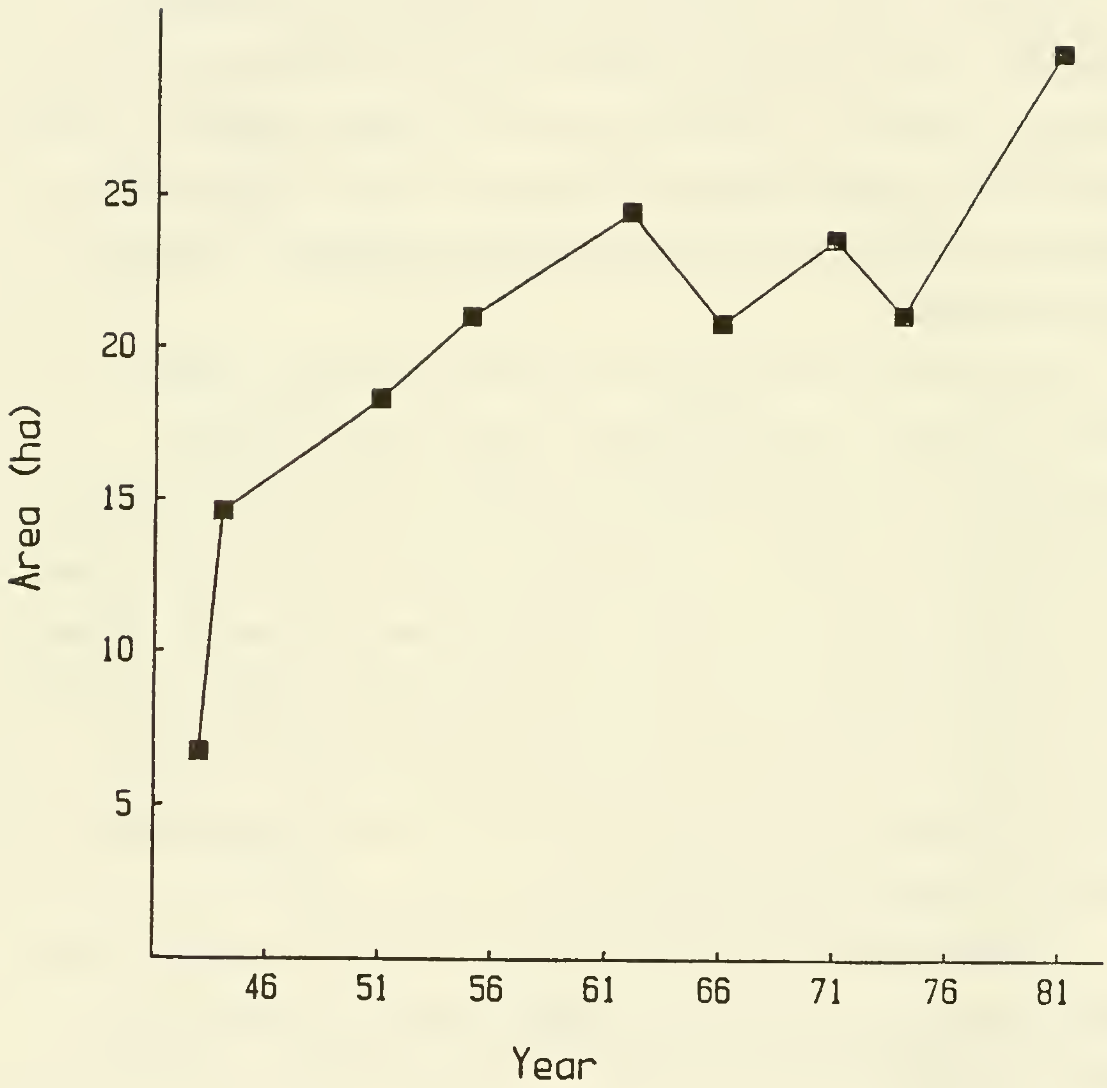

Figure 16. Eelgrass bed area (corrected for % cover) of the North side of Megansett Harbor from 1943 to 1981.

watershed has a moderate density of homes with on-site sewage disposal. Little eelgrass grows here because the inner Harbor has appreciable wave scour, and the outer harbor to drops rapidly to 6.0 m MLW. Nonetheless this site is interesting because it was the focal point of a large spill of No. 2 fuel oil on 16 September 1969 (Sanders et. al., 1980).

Because this is a high energy environment, the beds positions are somewhat variable between surveys. Nonetheless, beds on each side of the entrance of Silver Beach Harbor are present on most photographs, but show changes in boundaries. These beds are dense and persistent on all photographs including within one year of storms and ice scour. Nonetheless, the beds here are noticeably less dense and cover less area in April 1971 than prior to the oil spill. In 1974, eelgrass cover remains somewhat depressed, but by 1975 and 1981, these beds seem to have largely recovered. There is evidence that the concentration of fuel oil in the sediments was high enough to account for these changes (Costa, 1982).

West Falmouth Harbor

West Falmouth Harbor is a protected embayment with freshwater stream input primarily from . The watershed surrounding this bay is developed and there is evidence of water quality declines such as algal blooms and shellfish bed closures. This area was also impacted by a small oil spill in November 1970 (Sanders et al., 1980).

No early documentation of eelgrass abundance was discovered. Eelgrass was abundant outside West Falmouth Harbor and just within the bay in 1943 (Fig. 17). Eelgrass expanded considerably during the 1950's

and 1960's, but a November 1971 photograph shows that some beds had disappeared or had less cover than in 1966, particularly in the deeper parts of the bay, such as at the channel by the mouth of the bay. Like Wild Harbor, this decline could have been related to the oil spill because most other parts of Buzzards Bay do not a decline at this time, suggesting local conditions were the cause.

Waquoit Bay, Falmouth

A 100 to 500 m shoal is present on the eastern shore of Waquoit Bay, south of the Quashnet River. After the wasting disease, and prior to the mid-1970's, eelgrass was abundant on that shoal (Figs. 18 and 19). There is some question about the composition of vegetation along this shore in the 1938 photograph because a longtime shellfisherman (O. Kelly, pers. comm) claimed that *Ruppia* was the sole species on this shoal during a visit in 1937. If so, *Ruppia* was replaced by eelgrass in subsequent decades. By early 1970's eelgrass began to decline in this area, beginning first along the deeper bed margins and the innermost parts of the Bay. Virtually all eelgrass disappeared between the Quashnet and Little Rivers by the early 1980's, and no beds and few shoots were observed in 1985 and 1987 field observations.

In addition to these events on the eastern shoal, drift algae

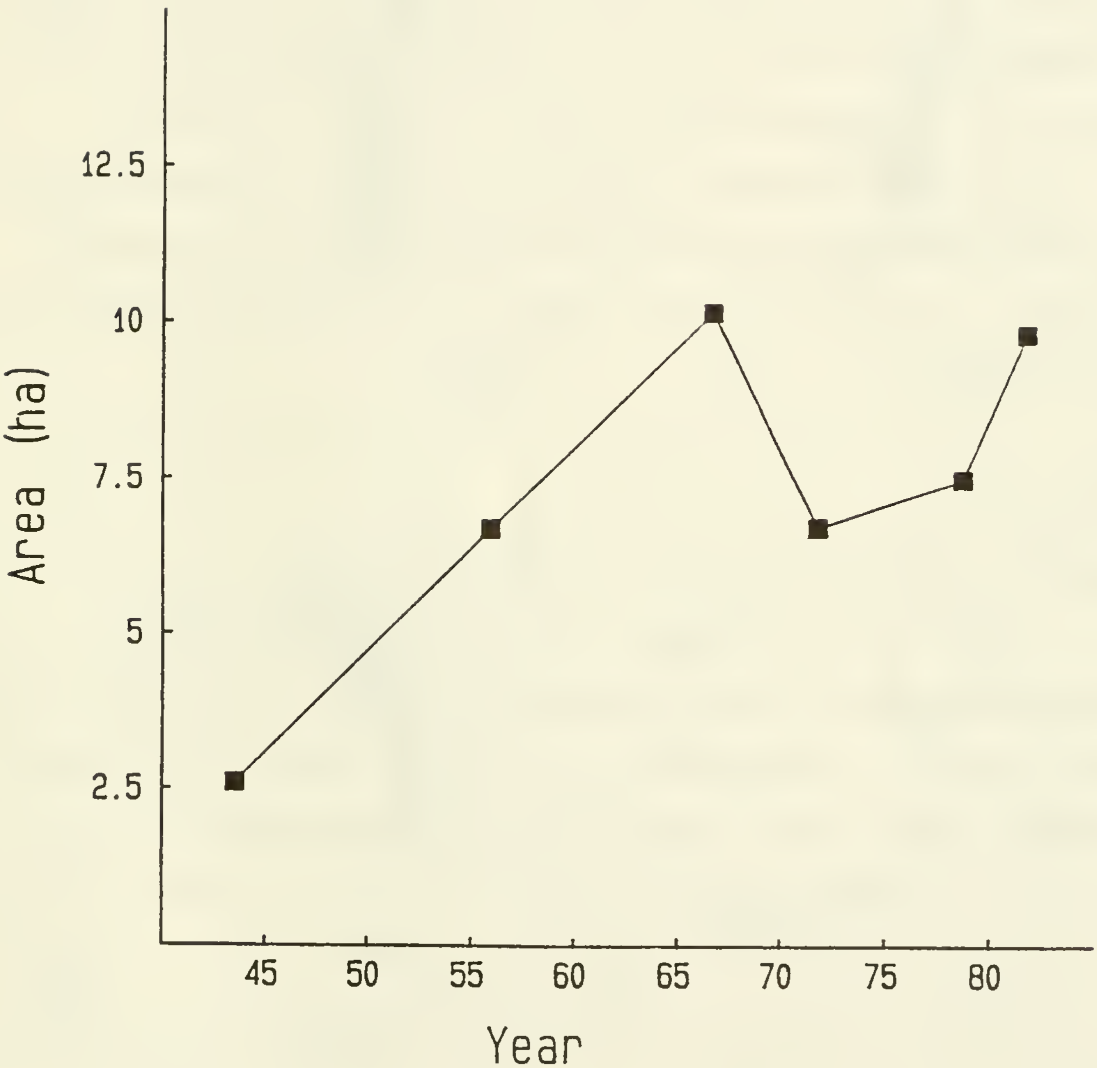

Figure 17. Eelgrass bed area (corrected for % cover) in West Falmouth Harbor between 1943 and 1981.

became more prominent in the deep central part of the Bay after 1960, Today *Cladophora* and other drift species accumulate to depths of 70 cm in places (Valiela and Costa, in prep). Sediment cores show that eelgrass was abundant in the central Bay prior to the wasting disease. Photographs and core data show that eelgrass returned there by the 1950's, but disappeared again between 1965 and 1973 (Chapter 3).

The increased growth of algae and the pattern of eelgrass decline in Waquoit Bay suggest that these events were related to nutrient loading. After 1970, eelgrass expanded only on the flood delta at the mouth of the bay.

Discussion

Impact of the wasting disease in Buzzards Bay

Documentation of eelgrass prior to the wasting disease is fragmentary, but all evidence suggests that eelgrass cover in Buzzards Bay equaled or exceeded present day abundance: Aerial photographs of Sippican Harbor, Marion taken before the wasting disease show that eelgrass was as abundant near the mouth of the bay in 1930 as in 1981, and even more abundant at the head of the bay during 1930. Sediment cores show that eelgrass was more abundant in several areas prior the disease (and in some cases 20 years later) than today. This is corroborated by photographs that show that eelgrass populations in some bays had greater coverage during the 1940-1960's than today. Fragmentary documentation of eelgrass distribution on old nautical charts demonstrate that eelgrass grew in the same areas prior to the disease as recolonized after. Residents have noted that eelgrass has

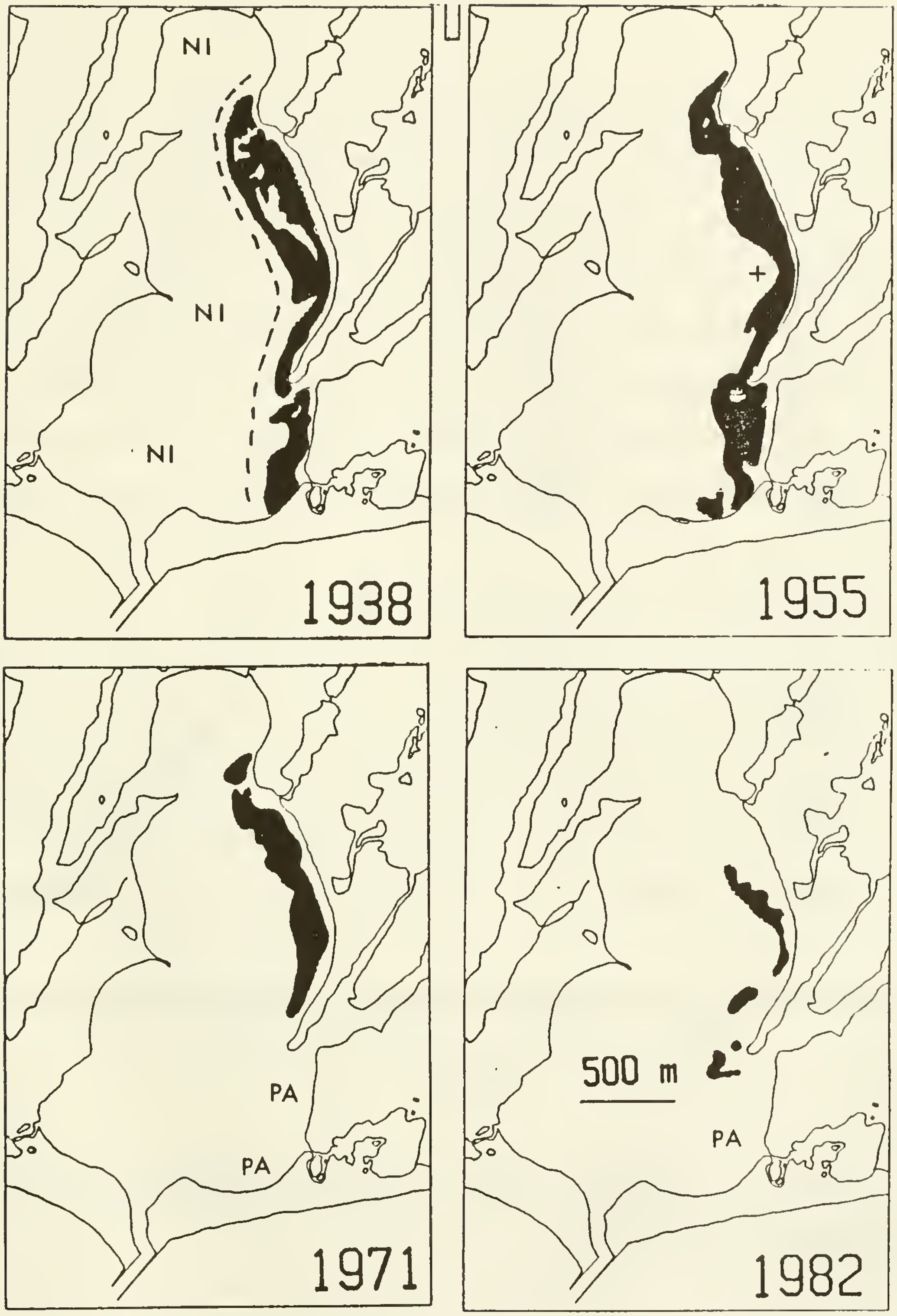

Figure 18. Eelgrass cover on the eastern shore of Waquoit Bay during four periods. Only vegetation within the dashed line (top left) was mapped. By 1987, all large patches of vegetation on the east shore disappeared.

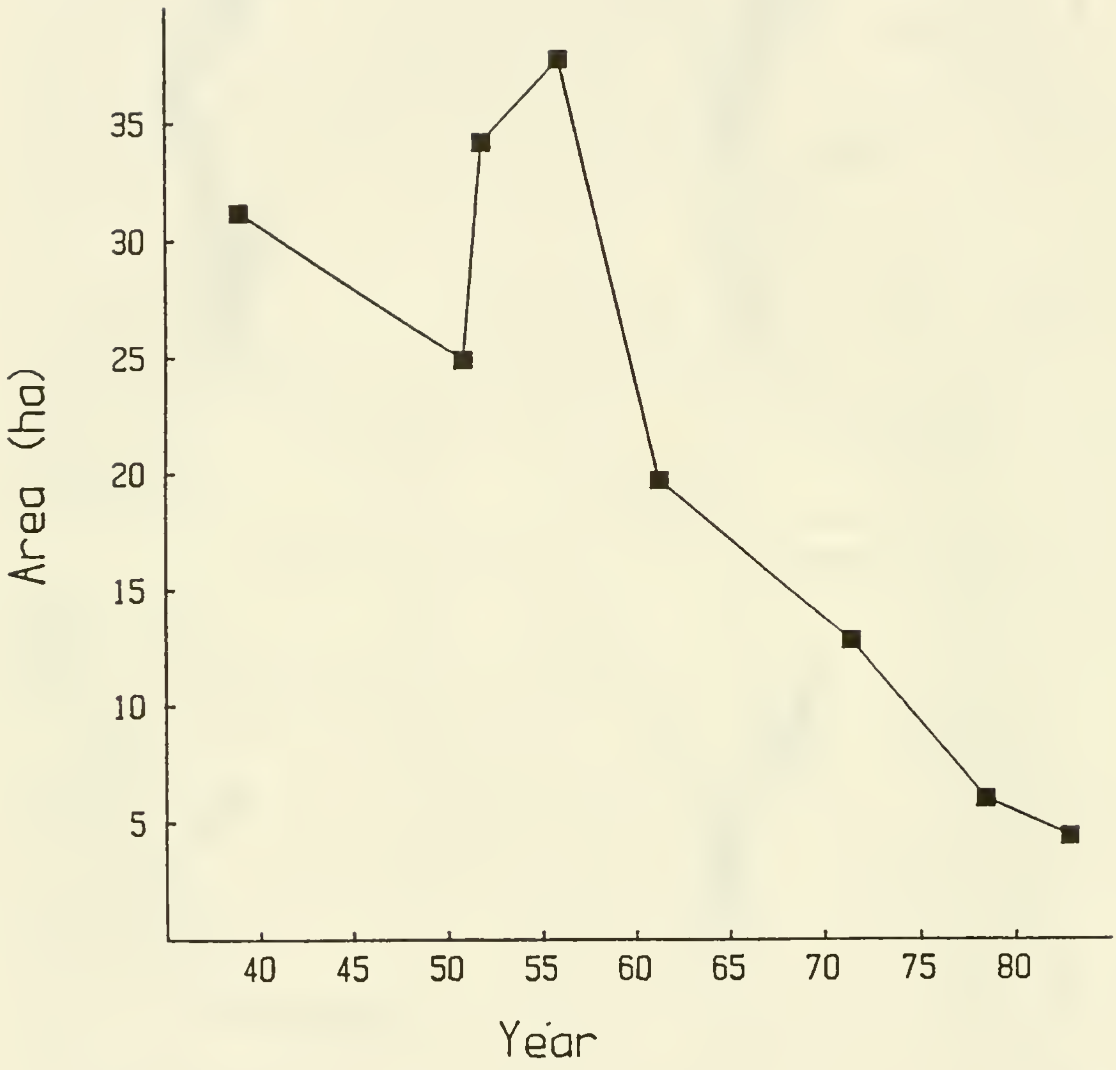

Figure 19. Eelgrass bed area in Waquoit Bay (adjusted for % cover) between 1938 and 1981.

not returned to some areas. Available published descriptions of eelgrass distribution around Cape Cod prior to the wasting disease also match or exceed the present abundance. For example, Allee (1919) in his survey of invertebrates described eelgrass in Quisset Harbor, Falmouth, as growing within 5 m of shore, and "continuous throughout" the bay. Today eelgrass grows primarily near the mouth and only to 2 m, and is absent from the less flushed and deeper parts of the bay. Davis (1913a+b) dredged eelgrass from greater depths in Buzzards Bay and Cape Cod than observed today.

In light of these observations, the assessment by Stevens et al., (1950) that eelgrass cover in upper Buzzards Bay equaled less than 0.1% of prior cover seems realistic, especially because the earliest photographs (6 to 10 years after the epidemic) generally show that surviving eelgrass beds in Buzzards Bay equaled 10% or less of the peak eelgrass cover observed today. In most areas, eelgrass did not begin to recolonize until the 1950's.

As reported elsewhere, the earliest photographs from Buzzards Bay show that eelgrass populations beds near streams and rivers survived or recovered soonest after the disease. Not noted earlier, were that some beds on the outer coast or in deeper waters survived as well. For example, eelgrass beds are abundant around Little Bird Island, Wareham, a shallow shoal 1 km off Great Neck where eelgrass is absent virtually absent. This occurrence can only be explained if this offshore population survived the disease. This bed is not unique, other beds on exposed coasts, often 100's of m from freshwater sources survived as well. The absence of records of surviving offshore or deep beds in

Buzzards Bay is not surprising because documentation in most areas was poor, and observations during the wasting disease were made from the surface, nearshore. Local observers noted at the time that living shoots occasionally washed from offshore areas (e.g. Lewis and Taylor, 1933). Little significance was attached to these observations, but in Buzzards Bay, these offshore beds were equally important in facilitating the recovery of eelgrass populations after the disease. In general, the onset of colonization of bare substrate was dependant on the distance from these refuge populations.

Cause of the wasting disease and the temperature hypothesis

Labarynthula causes all symptoms of the wasting disease (Short, pers. comm), but it is always present in eelgrass populations; diseased plants are common, but normally do not reach epidemic proportions. Therefore, what conditions in 1931-1932 led to the outbreak of the wasting disease? One possibility is that more virulent strains of *Labarynthula* may arise (Short, pers. comm). The transmission of a virulent agent, as Rasmussen (1977) points out, cannot explain the near instantaneous appearance of the disease throughout North America.

As stated earlier, the most popular hypothesis concerning the onset of the wasting disease is that abnormally high summer water temperatures and mild winter temperatures somehow made eelgrass more susceptible to a parasite (Rasmussen, 1977). Bulthuis (1987) rejected the supposition that temperature stresses eelgrass, because recent research has shown that eelgrass is so eurythermal, and an elevation of several degrees is insignificant. Also, water temperatures were not

elevated in all areas in Europe where eelgrass declined because of local climactic variations (Bulthius, 1987). The recent losses to disease in Great South Bay, New Hampshire during the 1980's (Short, 1985) were not associated with elevated temperatures, and again suggests that temperature elevation cannot be the sole explanation for disease outbreaks.

The observation that some beds offshore in Buzzards Bay survived the wasting disease does support the temperature hypothesis because beds in deeper water are insulated from the extreme temperature that occur in some shallow embayments. For example, in summer, shallow areas may be as much as 10 °C higher than temperatures recorded in well flushed areas (pers. obser., Allee, 1923a). This phenomenon may not be the sole reason for bed survival because some shallow beds along shore, not near freshwater sources, survived or quickly recolonized as well.

Temperature and climactic conditions in Massachusetts during the early 1930's have not been critically analyzed. Were water temperatures in Buzzards Bay high during the early 1930s as observed elsewhere? Water temperature in shallow coastal waters correlates with air temperature. In eastern North America, mean winter temperatures cycle every twenty years (Mock and Hibler, 1976). This short-term oscillation is superimposed on a one hundred cycle of winter temperature oscillation, and the coincidence of peaks and nadirs of these cycles resulted in the warmest winter ever recorded in the east north central US during 1931-32 (October - March mean = 3.7 °C), and the coldest in 1977-78 (October - March mean = -1.4 °C; Diaz and Quayle, 1978). Air temperature data for Boston show that both that the summers of 1931 and

1932 had three times the number of days above 32 °C (90 °F) than did the average for all other summers between 1900-1935 (Chief of the Weather Bureau Reports). Localized differences in this trend exist, and in New England, the winter of 1932-33 was warmer than the previous winter. Furthermore, New England had a warmer winter in 1889-90, and one nearly as warm 1912-13.

February water temperature in Woods Hole is generally the coldest month of the year, and August the warmest. Water temperature data for Woods Hole is not available for 1931, but is available for a station in Nantucket sound, 30 km to the East, and a station in Rhode Island, 50 km to the west for this and other years. At these neighboring stations, mean February and August temperatures were warmer in 1932 than 1931 (Bumpus, 1957), which also coincides with air temperature trends described above for New England. In Figures 20 + 21, February 1931 temperature data was estimated from a multiple linear correlation from these stations ($r2= 0.62$, $\alpha > 0.05$). August temperatures in Woods Hole do not correlate well with the other stations and was conservatively estimated as equal to the 1932 data.

Like winter air temperatures over the Northeast U.S., water temperature in February 1932 was the warmest since 1890, but February 1913 was only slightly warmer than usual (Fig. 20, top). Furthermore, many subsequent years had February water temperatures nearly as warm or warmer. August water temperature in Woods Hole (Fig. 20, bottom) show less distinct cycling, and is out of phase with the winter climate

cycle. Hence, August water temperature 1932 was also the warmest in 40 years, but warmer events occurred often in subsequent decades.

These data substantiate Rasmussens' view that 1931 and 1932 were the first consecutive 2 year period of warm summers and winters in decades. Nonetheless, subsequent two year periods (1949-1952, 1969-1970, 1974-1975) had winter and summer water temperatures that were as warm or warmer than the 1931-32 event (Fig. 21), but no general declines in eelgrass were reported in New England, or apparent on photographs of Buzzards Bay. A decline between 1949 and 1952 could have gone unnoticed, because eelgrass populations had only partly recovered in most areas. A decline during the late 1960's or mid-1970's, however, would have been much more apparent because eelgrass had recovered considerably by that time and there had been no recent major storms or ice accumulation that could cause a decline that could be mistaken for disease-caused declines.

One additional line of evidence contradicts the temperature hypothesis. Past declines of eelgrass in New England (1894, and 1908) reported by Cottam (1934) do not coincide with the warm summer and winter pattern. In 1894, the winter was cool, and the decline came 4 years after a record breaking warm winter. The 1908 event was not characterized by unusual weather.

These observations do not rule out the possibility that warm temperatures played a role in the 1931-32 decline, but suggest that

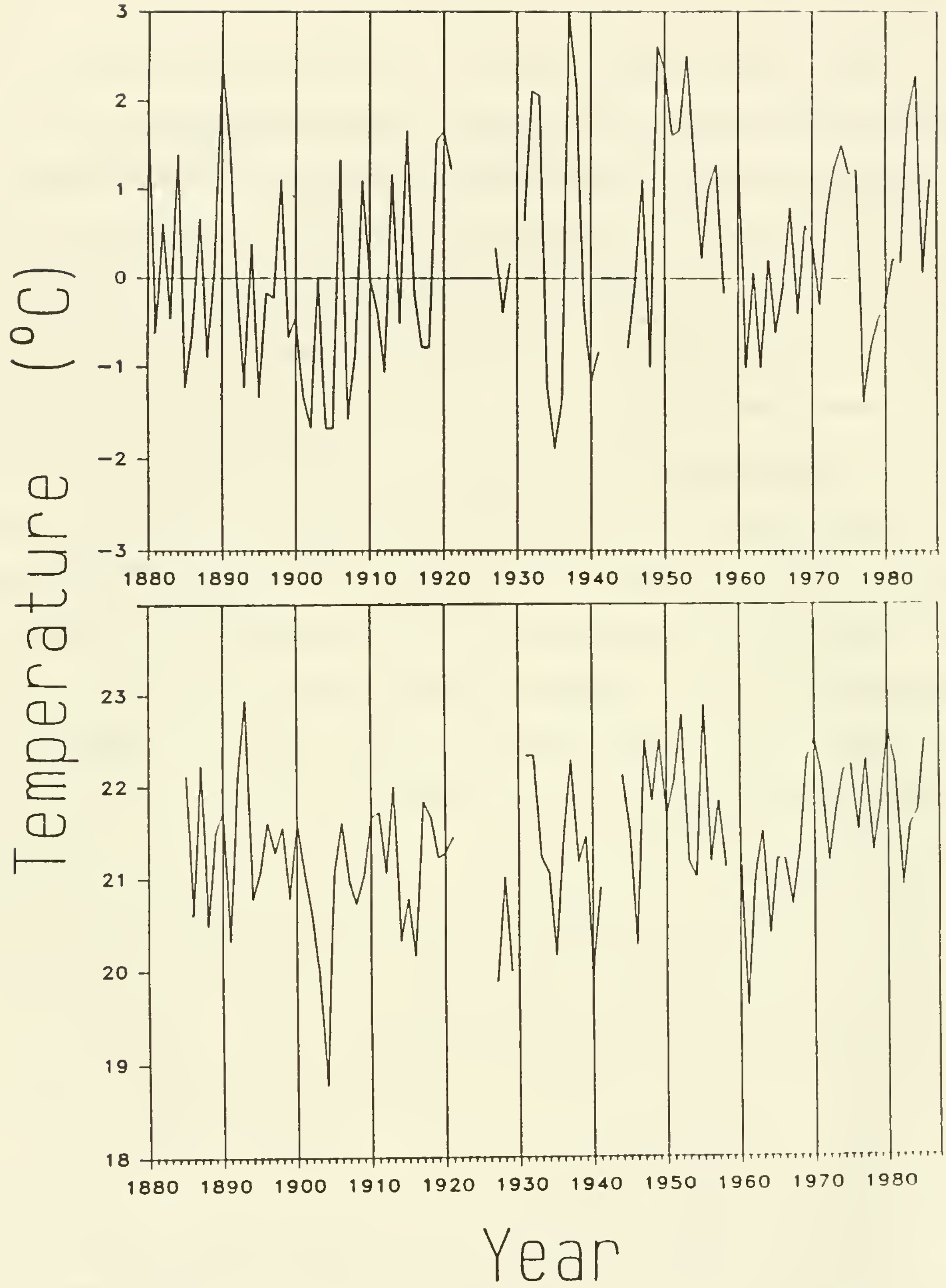

Figure 20. One hundred year record of water temperatures in Woods Hole. Top: Mean February temperature in Woods Hole: 1880-1986. Bottom: Mean August water temperatures in Woods Hole for the same period. Data 1931 was estimated (see text).

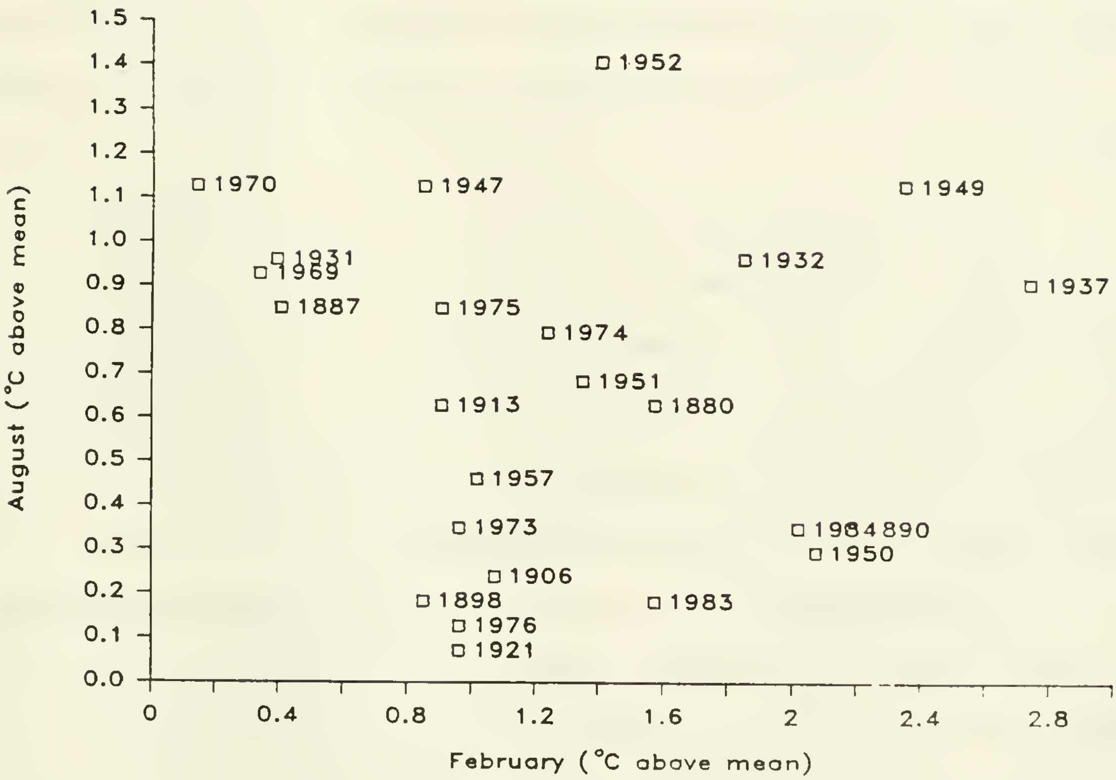

Figure 21. Temperature deviation above the long-term mean for August and February in Woods Hole for 96 years of data between 1880 and 1987.

Years with temperatures below the mean for either month are below the lower limits of the graph and not shown.

General patterns of recolonization

Regionally, recovery was slow, and the greatest increases in eelgrass abundance occurred between 1955 and 1970. By the 1980's, eelgrass had saturated most available substrate, but eelgrass populations continue to expand in some areas today, and residents note that eelgrass has not fully recovered to its former abundance in certain bays.

The onset of recolonization occurred mostly during the 1940's and early 1950's. In some areas, recolonization did not begin until the 1960's or later because they were remote from refuge populations, and eelgrass propagation is slow over 1000's of meters. This pattern explains why some populations in this region and elsewhere (e.g., den Hartog, 1987) are still recovering 50 years after the decline.

The colonization of West Island, Great Neck, and Megansett Harbor by eelgrass beds that survived in offshore or euryhaline environments shows that eelgrass beds in estuaries or near fresh water sources were not the sole refuge populations that later recolonized Buzzards Bay, and were less important in the colonization of offshore areas and exposed coasts.

Around Buzzards Bay, once eelgrass began to colonize an area, the time to reach peak abundance varied markedly. On a small scale (below 10 ha) growth is typically logistic, and habitat is saturated in 8 to 15 years (Costa, 1988 and in prep.). In some locations, such as on the shallow shoal south of Indian Neck on Great Neck, Wareham, most population growth occurrred during a 4 y period (1962-1966), a few years

after the first patches of eelgrass appeared.

The percent cover of eelgrass beds at peak abundance also varied among sites. In high energy environments like Megansett Harbor, Falmouth, wave scour and storms frequently remove patches of eelgrass of various size, so some habitats never exceed 50% cover, even over decades. In shallow areas like this, eelgrass beds survive and recolonize in the troughs of migrating sand waves (Fig. 21a). In contrast, eelgrass beds eventually cover virtually all of the bottom in quiescent areas.

Differences in both colonization rate and peak cover can be explained by differences in disturbance size, disturbance frequency, vegetative growth rate, and seedling recruitment rate that can be measured from photographs. These variables were included in a computer simulation that accurately predicted changes observed on sequences of photographs (Costa, 1988 and in prep.). Results of this simulation suggest that physical removal of patches of eelgrass less than 10 m^2 have little effect on rate of colonization or peak cover, even when 25% of the bed is removed each year. Other disturbances, such as declining water quality or catastrophic storms may lead to sizeable and longlasting losses.

The pattern of eelgrass colonization on a larger scale (100's to 1000's of ha) is distinct from the small scale pattern of colonization. On large parcels of coast, such as around Great Neck (above) or high energy areas like Wianno Beach on Cape Cod (in prep.) eelgrass took 20 to 30 years to reach peak abundance after onset of colonization. Growth on a large scale is not logistic, rather staggered or linear because of

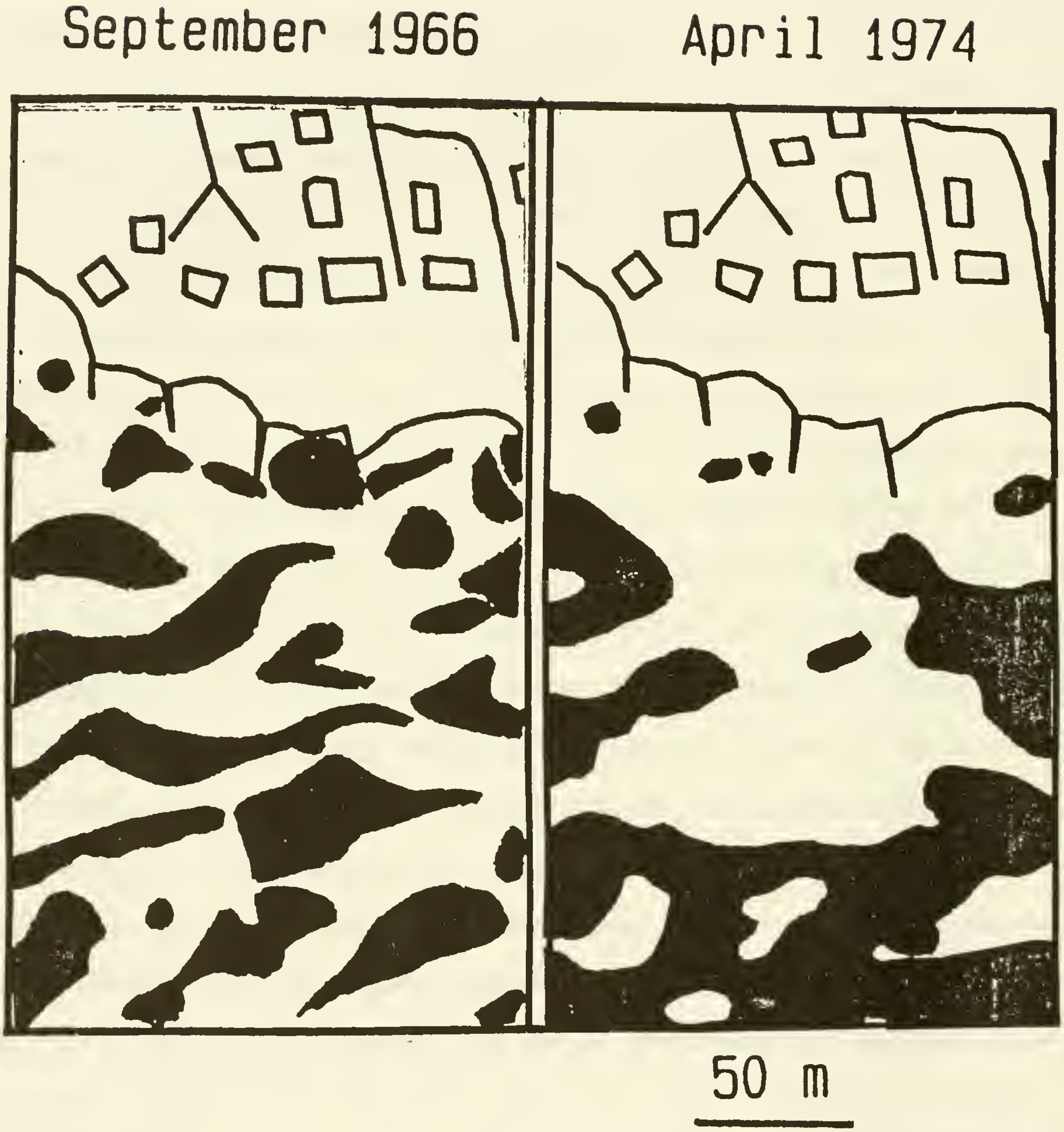

Figure 21a. Eelgrass beds growing between sand waves (near Little Harbor Beach, Great Neck Wareham). Eelgrass cover on this habitat did not change appreciably between the two years shown. This demonstrated that colonization and growth kept up with losses from sand wave migration. Most of these beds, however, were destroyed by ice scour and winter storms during the late 1970's.

stepwise colonization, hydrographic and geographic isolation, and heterogeneity of the substrate (above and Costa, 1988).

Causes for recent declines

Superimposed on the long-term pattern of gradual recovery and continued expansion after the disease are local declines that were the result of other natural or anthropogenic disturbances. Eelgrass populations generally recovered from natural disturbances within ten years. For example, severe storms in 1938, 1944, and 1954 destroyed eelgrass in some exposed or shallow areas in Buzzards Bay and Cape Cod (above and Costa, 1988). In less exposed areas, eelgrass recolonization was only slowed by these disturbances. Ice scour often removes eelgrass in shallow areas, as was evident along the shallow margins of beds in East Bay, Fairhaven and along Great Neck, Wareham during severe winters in 1977-1979. In shallow Bays like Apponagansett Bay, So. Dartmouth and the Westport River basin, ice accumulation coincide with major fluctuations in eelgrass abundance.

New losses due to human perturbation have been longer lasting. The disappearance of eelgrass in the north end of the Westport Rivers, Apponagansett Bay, Dartmouth; Little Bay, Fairhaven; Wareham River, parts of Sippican Harbor, Marion; Clarks Cove, Dartmouth; Waquoit Bay, Falmouth (on Vineyard Sound), and other coastal lagoons on Cape Cod (in prep.) appears to be due to decline in water transparency from nutrient loading because these areas have conspicuous macroalgal growth, poor water transparency, abundant periphyton, prominent gradients of maximum eelgrass growth and related declines in water quality such as shellfish

and beach closures. Resuspension of sediments by propeller wash and subsequent decline of light availability to eelgrass beds may be a contributing factor for declines in some shallow bays.

Dense accumulations of drift algae that often result from nutrient loading contribute to eelgrass loss because drift material can smothers young eelgrass seedlings an adult shoots (pers. obs.) and increases in abundance of drift algae have been related to eelgrass losses elsewhere (Nienhuis, 1983). Drift algae were not quantified in this study but it is apparent from aerial photographs that this material has been increasing in many bays during recent decades. Such changes in bottom flora can be verified by analysis of core sections for changing chlorophyll degradative products (Brush, 1984) and stable isotope ratios (Fry et al., 1987), and should be studied.

The loss of eelgrass from New Bedford Harbor could be due to any number of causes including declining water quality, toxic pollutant accumulation in the sediments (PCBs and heavy metals among others), or changes in hydrography resulting from the construction of hurricane barriers there. No study of the effects of PCBs on eelgrass have been undertaken, and no studies on long term changes of water quality have been made in this area, therefore no conclusion can be made on the exact causes of declines in New Bedford until further studies are conducted.

There is no evidence for recent large scale declines of eelgrass populations due to new outbreaks of the wasting disease as has been reported elsewhere (Short et al., 1986). In two photograph sequences (such as in Sippican Harbor during the early 1970's, Apponagansett Bay during the early 1950's), isolated declines in eelgrass do not coincide

with ice accumulation or storms. These declines are enigmatic, but are probably linked with pollution events, because both areas have been developed for many decades, and have had variable water quality in the past.

Most recent declines in eelgrass abundance in Buzzards Bay that are not related to physical removal have occured in areas where there are large anthropogenic inputs in relation to local flushing rates. There are unanswered questions concerning human impact on eelgrass abundance, but it is clear from this and other studies that eelgrass is sensitive to water quality decline. Therefore, in light of increasing rate of developement and discharges along the shores of the Buzzards Bay, it is likely that new declines in eelgrass cover will occur.

Chapter 5

Management considerations of eelgrass populations in Massachusetts

Resource assessment

It is generally agreed that eelgrass beds are important to the ecology of the coastal zone, but there is no consensus on how to manage this resource. The newly realized ecological, economic, and aesthetic value of eelgrass beds and the biological community they support has brought them under some local, state, and federal coastal resource regulations. Because there is no consistent management policy concerning eelgrass beds, it is worth considering how governmental agencies in Massachusetts manage these communities.

In general, the effects of eelgrass bed removal on coastal production and ecology are rarely considered. To date, most decisions in Massachusetts relating to eelgrass beds have centered on physical removal or damage from dredging projects, or pier construction. Rarely are changes in water quality induced by these or other projects considered, but potential changes in water quality may be weighed when the overall "health" of a bay is considered. Often the decision to dredge through an eelgrass bed is ultimately based on whether these beds also coincide with shellfish beds.

Federal, state, and local laws

The coast of Massachusetts is regulated principally by town conservation commissions, local planning boards, the State Department of

Environmental Quality Engineering (DEQE), Army Corps of Engineers, Massachusetts Environmental Protection Agency (MEPA), and the State Coastal Zone Management (CZM). Most state regulations concernining coastal impacts are included in the state Wetland Regulations, (310 CMR 10.00).

In these regulations, eelgrass beds may enjoy protection under the law as "land under salt ponds" (10.33) where no project may affect "productivity of plants, and water quality". In "land containing shellfish" (10.34), and "land under the ocean" (10.25), there are broad guidelines protecting "water circulation", "water quality", and "marine productivity". Section 10.26 specifically states: "projects shall be designed and constructed, using best available measures so as to minimize adverse effects on marine fisheries caused by .... b) destruction of eelgrass (*Zostera marina*) beds". Thus, while destroying eelgrass beds is not prohibited, damage should be minimized.

In practice, coastal projects often do not go beyond the local conservation commissions. If they do, most decisions are managed by DEQE at the state level, but other state agencies (e.g. MEPA) may also be involved. In addition, CZM provides an advisory role at all levels of the decision making process and checks for consistency in local and federal regulations. Curiously, CZM policy guidelines (301 CMR 20.00) do not specifically include eelgrass beds as valuable underwater habitat, but in practice, this organization is interested in protecting eelgrass communities.

Large construction projects frequently must be approved by the US Army Corps of Engineers which considers eelgrass beds in there

decisions. In recent years, the Corps has sponsored eelgrass transplant studies as a form of mitigation to disturbances (e.g. Fonseca et al., 1979, 1985; Goforth and Peeling, 1979).

Towns often have bylaws which may broadly cover coastal impacts, but no towns in Buzzards Bay have any bylaws specifically protecting eelgrass. Some local bylaws (e.g. Title V Amendments) extend the distance of septic tanks from shore (the "setback"), to further reduce the risk bacterial and viral contamination of shellfish. These laws indirectly benefit eelgrass beds because increased distance of septic tanks from shore reduces nutrient loading of bays (Valiela and Costa, in press).

Town conservation commissions may have broad powers to consider aesthetic and ecological impact of a project. While their decisions are based on both local and state laws, their decision is independent of state decisions, and technically they may prohibit a project even if approved by the state, although in practice, this is infrequent.

Most direct management of eelgrass beds, if any, is conducted by the town shellfish warden. In some towns, the shellfish warden may view existing eelgrass beds as valuable habitat, as is the case in Fairhaven, and harvesting shellfish in eelgrass beds may be discouraged. In other towns the shellfish warden may view eelgrass beds as a nuisance weed that reduce the quantity or quality of shellfish harvested, and the removal of eelgrass has been considered. Methods of eelgrass removal in the past were more extreme, and the application of the herbicide 2,4-D was attempted in Fairhaven in the 1960's (Fiske et al., 1968).

If there is an active policy by environmental managers today, it is usually toward conservation of eelgrass. In Westport, a large parcel of tidal flat, with extensive eelgrass coverage, is set aside as a shellfish refuge. On Nantucket, a multimillion dollar scallop industry is based within extensive eelgrass beds within a coastal lagoon. To reduce physical damage to the eelgrass beds by the scallop dredges, the shellfish warden has persuaded local fisherman to remove some weight from their scallop dredges so that they skim the surface, cropping eelgrass leaves, but leaving behind roots and rhizomes to regenerate.

At all levels of management, lack of knowledge about the importance of eelgrass, eelgrass bed locations, and the effects human impacts, has limited proper management of this resource.

Implications of changing eelgrass abundance

This study raises several questions relating to the management of eelgrass beds and interpretation of their changing abundance. It is apparent that most eelgrass disappeared in Buzzards Bay as a result of the wasting disease, then gradually recovered over many decades. Superimposed on this trend are complex patterns of destruction and recolonization driven by catastrophic storms, ice scour, and anthropogenic disturbance.

One consistent trend observed was the continual expansion of eelgrass on the outer coast and well flushed areas. Here, occasionally moderate declines in eelgrass abundance result from ice scouring and catastrophic storms, but these beds typically recover after several years. In contrast, many poorly flushed bays did not recover

appreciably after the wasting disease, or showed major new declines with no subsequent recovery. These areas had known histories of anthropogenic disturbances such as fecal pollution, sediment resuspension, and wastewater loading through either direct discharges or via contaminated groundwater or stream flows. This trend is alarming because, unlike natural disturbances, eelgrass will not recover where human perturbation persists. Furthermore, many of these estuarine areas supported refuge eelgrass populations that facilitated eelgrass recovery after the wasting disease. Because beds in many of these areas have now disappeared, a recurrence of a wasting disease will have a longer lasting impact on the coastline.

This study adds to the growing literature showing seagrasses may disappear because of water quality decline, and that the disappearance of eelgrass may be a early warning sign that important changes are occurring in a coastal ecosystem.

Future monitoring

Throughout much of this report, eelgrass abundance was documented using fragments of information from many sources. A more thorough understanding of eelgrass dynamics can be achieved through continuous monitoring and by analyzing sediment cores.

The easiest way to monitor changes in eelgrass abundance is through periodic aerial surveys together with some field verification. This is a highly desirable approach because other aspects of coastal

ecosystems, such as erosion rates, harbor usage, salt marsh bed loss, and drift algae accumulation will be documented as well.

One difficulty of using previous aerial surveys in this study was that the imagery was not taken with submerged features in mind, and field conditions were often unconducive to analysis. It is advisable that any town or agency conducting an aerial survey of the coastal zone, do so using the guidelines in Table 1. Routine vertical aerial surveys should be conducted at least once every 3 years, especially in valuable resource areas or embayments undergoing rapid development.

Sediment core analysis is the most accurate way of assessing past local fluctuations in eelgrass abundance during this and previous centuries. Furthermore, the physical and chemical characteristics of core sections, along with the remains of plants and animals, can document long term changes in nutrient levels, shellfish abundance, sediment depositional rates, rates pollutant inputs, nutrient loading, and macroalgal and periphyton abundance (Brush and Davis, 1984; Fry et al., 1987, unpub. data). Sites for coring should be chosen carefully, and best results are achieved in quiescent, depositional areas, away from erosion and dredging influences (Davis, 1985). Together with aerial surveys and other documentation, sediment core analysis is a powerful tool for understanding the recent ecological history of coastal waters.

Table 1. Guidelines for taking aerial photographs to maximize interpretation of submerged features.

The guidelines and months are listed in approximate order of desirability.

- -during October, September, August, July, June, November, and May
- -within 2 hours of low tide
- -low sun angle, preferably early morning
- -low wind velocity (< 5 kts)
- -at least 2 days after any severe storm or rain event
- -color photography preferable to black & white, IR is undesirable
- -overexposure by 1/2 to 1 f-stop
- -polarized filter

One intriguing possibility that needs study is that the depth of eelgrass growth throughout the Bay may have declined slightly. If prior to urban and industrial inputs in Buzzards Bay, eelgrass grew 0.5 m deeper in each habitat throughout the region and was present in coves in which it is absent today, then total eelgrass area may have been 50 % greater than todays cover. This hypothesis is testable because changes in eelgrass depth distribution and relative contribution of eelgrass to primary production can be assessed by analyzing sediment cores.

Eelgrass can sequester heavy metals in its leaf tissue, and it has been suggested that eelgrass be used as an indicator organism for this type of pollution (Brix et al., 1983).

Mitigation efforts

In recent years there has been considerable effort to mitigate eelgrass habitat loss by transplanting eelgrass into areas where it was removed, or if that proves unfeasible, transplant it to other suitable habitat (Boorman et al., 1978; Churchill et al., 1978; Fonseca et al., 1985; Goforth and Peeling, 1979; Kenworthy et al., 1980; Phillips, 1974, Robilliard and Porter, 1976). There are several problems inherent in mitigation efforts in general. First it may take many years for an eelgrass community to fully recover after initial colonization or transplantation.

Often, coastal dredging increases depths to such an extant that habitat area is permanently lost. In these cases, bare areas nearby may be chosen as the site of transplantation. Because there may be

hydrological or physiological reasons for the absence of eelgrass in these areas, transplant efforts to these areas often fail (Ranwell et al., 1978).

Nonetheless, sufficient number of projects have succeeded in reestablishing eelgrass where it has been removed. This approach, while experimental, has a role in coastal management. For example, transplantation may facilitate a more rapid recovery of eelgrass populations where there have been large losses due to storms, disease, or pollution. Transplanting as a form of mitigation, however, should not be used to rationalize incremental permanent loss of habitat.

Future management

Eelgrass beds are not well protected under current Massachusetts regulations, and a coherent management policy regarding eelgrass beds should be formulated, especially because eelgrass is declining in some Bays. Because salt marshes are rigorously protected in Massachusetts, as maps of eelgrass abundance become available, the question will arise: should eelgrass beds be regulated as carefully as salt marshes? To answer this question, comparisons between the two communities can highlight potential management strategies.

Eelgrass beds are more abundant and productive than salt marshes, and are a dominant feature of nearshore waters in Buzzards Bay. These two ecosystems are host to different communities of organisms, and each serves a different ecological role. Salt marshes build dense layers of peat over decades and centuries which become an intrinsic part of the stability and biology of those communities. Eelgrass beds do not form

peat mats, and although they change the chemistry and biological components of the sediments (Orth, 1973, 1977), the time to create an eelgrass habitat after initial colonization is shorter than the time to create a mature salt marsh community. Furthermore, the range of habitats that eelgrass can colonize is more diverse and expansive than the habitats available to salt marshes. Some eelgrass beds are seasonal or may appear on marginal habitat only intermittently.

Given these characteristics of eelgrass beds, the main priority in regulating physical disturbances should be to prevent alterations to the environment that permanently eliminates eelgrass habitat. Dredging and construction in shallow, poorly flushed bays is especially critical because water transparency in these areas is usually poor, and channels dredged for boats are often so deep and so disturbed that eelgrass can never grow there, and habitat area is lost. Construction of a single private boat channel may result in the removal of only 5% or less of existing eelgrass cover in a bay, but permitting channels to be dredged to every private dock may result in intollerably large losses.

Small physical disturbances like eelgrass removal during shellfish harvesting with rakes or tongs are probably unimportant for bed survival under low intensity (Costa, 1988, and in prep.), but high intensity shellfishing efforts, or continued dredging from boats can remove large areas of eelgrass beds, as well as increase sediment resuspension and decrease water transparency.

Past declines of eelgrass due to physical removal, however, have been less important in Buzzards Bay as a whole, than losses due to general declines in water quality. This is understandable because

eelgrass beds are subtidal, and their distribution is light limited. In contrast, protecting salt marshes from nutrient loading is rarely an issue, because salt marsh production is enhanced by added nutrients (Valiela et al., 1975).

Because water quality declines are often due to many sources, and often difficult to quantify or assess, some managers view protection of eelgrass beds from water quality declines as uneconomical or unworthy. This view is short sighted, because eelgrass beds are closely linked to the ecology of coastal waters. Many other species besides eelgrass are also affected by water quality declines or disappearance of eelgrass. Beaches and shellfish beds may be closed due to fecal coliform contamination. Shellfish habitat may disappear because dense growths of drift algae form an impenetrable layer preventing oxygenated water from reaching the bottom (Lee and Olsen, 1985), smothering bivalves and other infauna. This dense growth may create such a high oxygen demand during quiescent summer periods that anoxic events may occur resulting in fish kills. Excessive algal growth sometimes release displeasing odors or cover beaches, making them unaesthetic. Other synergistic effects are now being realized. Algal growth, decreased water transparency, and nutrient loading facilitates fecal coliform survival or even promotes growth (Heufelder, 1985).

Thus, eelgrass beds are merely one component of coastal waters that are sensitive to declining water quality. In many areas, the loss of eelgrass could have been used as an early warning for more damaging changes that were to occur; that is, eelgrass bed declines may be used as a tool for diagnosing the "health" of a bay. Protecting water

quality should be a primary goal of coastal managers, not only because eelgrass beds are protected, but because other valuable resources are protected as well.

Water quality protection

Declines in water quality are due to many sources, some of which are difficult to control. For example, resuspension of sediments caused by boat motor use in shallow bays can only be reduced if either there is less boat traffic, enforced speed limits, or exclusion zones. Dredging projects not only eliminate eelgrass habitat, but generate high sediment loads. Some operations such as "jet-clamming",--the harvest shellfish by resuspending large volumes of sediment--could potentially have strong impacts on water quality because this process creates large sediment plumes and releases nutrients from sediment pore water. Serious questions must be answered before this technique becomes widespread.

Land based sewage disposal nearshore and sewage discharge offshore are two of the most serious problems affecting Buzzards Bay. New Bedford now discharges secondarily treated sewage offshore. The turbid plume from this outfall is conspicuous from air, and the several hundred meter wide plume often stretches 1000's into waters of neighboring towns.

Smaller outfalls from street run-off are common throughout the region. In some bays, nutrient inputs through these is small compared

to other sources (Valiela and Costa, in press), but they may be important sources of pathogens and other pollutants (Heufelder, 1985).

A more widespread problem in the region is the siting of septic tanks nearshore. One of the difficulties with coastal management in Massachusetts is that nutrients are not considered pollutants. Septic tanks and leaching systems are designed to reduce contamination of bacterial pathogens into groundwater; even a properly constructed septic tanks release large volumes of nutrients into the groundwater. When the State considers an application for a septic tank nearshore, it considers only the impact of a single proposed project on public health, rather than the effects of similar projects on water quality and nutrient loading. Because it is difficult to demonstrate that nutrients from a single septic will have a deleterious impact on a bay, such projects are usually approved, even if serious water quality declines would occur if every parcel of land along shore were similarly developed.

Presently, Massachusetts guidelines specify that these systems may not be placed within 15 m (50 ft) of wetlands or bodies of water (the "setback"). Many towns have set their own stringent setback bylaws, because the state regulations are viewed by many as inadequate to protect the publics interest in the coastal system. This is a positive step, but what is needed is town planning boards to set maximum nutrient loading limits for watersheds, and State managers to accept nutrient loading as a form of pollution, and hence regulate it.

Appendix I--Repositories of aerial photographs and nautical charts used in study.

Aero Service Division
Western Geophysical Company
8100 Westpark Dr.
Houston, TX 77063
(713) 784-5800

Col-East, Inc.
Harriman Airport
North Adams, MA 01830
(413) 664-6769

Lockwood, Kesseler & Bartlett, Inc.
1 Aerial Way
Syosset, NY 11791
(516) 938-0600

Lockwood Mapping Inc.
1 Aerial Way
Syosset, NY 14623

WHOI Woods Hole Oceanographic Institution
Woods Hole, MA 02543
(617) 548-1400

James W. Sewall Co.
147 Center St.
Old Town, ME 04468
(207) 827-4456

Town offices in Falmouth, Bourne, Wareham, Dartmouth, New Bedford, Fairhaven, Mattapoisett, and Marion

New Bedford Whaling Museum
New Bedford, MA 02740

Woods Hole Oceanographic Institution
Document Archives
Woods Hole, MA 02543
(617) 548-3705

Agricultural Stabilization and Conservation Service
Aerial Photography Field Office
US Department of Agriculture
2222 W. 2300 South
PO Box 30010

Appendix II

A detailed description of eelgrass in Buzzards Bay

Introduction

In this section, I provide a detailed description of eelgrass distribution in Buzzards Bay, and include numerous details on local subtidal physical, biological, and hydrological features. My intent in providing this information is to aid scientists and managers understand the factors that may affect to eelgrass distribution, to demonstrate the diverse nature of eelgrass communities in Buzzards Bay, and to aid others in the analysis of aerial photographs of the region.

I include eelgrass beds with as little as 10% cover, therefore Appendix III (% cover of beds) should be referred to when studying these maps. In this report, "eelgrass habitat area" refers to the area in which eelgrass is an important component of the bottom, and "eelgrass bed area" refers to area corrected for percent cover.

Westport (Figs. 1 + 2)

The distribution of eelgrass shown in the East and West Branches of the Westport River was based on aerial surveys taken 15 June 1982 and 5 November 1979, information from the town shellfish warden, and field observations in the West Branch on 9 August 1984. The distribution of eelgrass in the East Branch was not field verified and was primarily based on photographs and descriptions by the warden.

Beginning in 1984, eelgrass extensively colonized mudflats in the lower half of the Westport Rivers for the first time in recent memory of

local residents. Because the photographs used were taken before these changes, the distribution of eelgrass shown in West Branch, Figure 2 was based primarily on field observations. Eelgrass beds in the East branch could not be mapped because of lack of field observations, glare on the 1982 imagery of the East Branch, and low eelgrass abundance in 1979 imagery.

The beds that appeared on the tidal flats in the West Branch during 1984 were composed of dense, short, vegetative and reproductive shoots that grew from seed in June and July. In one of these beds (between Great and White Flats), shoot density was 627 shoots m^{-2} (n=8, se=68), and aboveground biomass exceeded 200 g m^{-2} (n=2, se=12). Flowering shoot densities were 179 m^{-2} (n=8, se=38.4), and the seed production exceeded 15,000 m^{-2} y^{-1}. Because these beds appeared late in the growing season, most flowers were unfertilized at the start of August, which is atypical in the region. In deeper channels, most shoots were vegetative.

The cause of this recent recolonization is unclear, and this estuary has undergone sizable fluctuations in eelgrass abundance in the past (Chapter 4). These new beds accounted for at least a 30% increase in eelgrass cover in this estuary over one year. Ice-scouring and freezing caused moderate loss of these beds during 1984-1985, but they regrew in subsequent years (D. Roach- town of Westport shellfish warden, pers. comm). Two years after the 1984 eelgrass expansion scallop catches were the best in many years (Alber, 1987). Whether the increased eelgrass habitat area enhanced scallop recruitment needs further study.

Today, eelgrass grows as far north in the West Branch as Judy's Island and Upper Spectacle Island on the East Branch. These limits probably do not correspond to the lower limits of salinity tolerance in eelgrass because shellfish such as Mercenaria are found north of these areas (D. Roach, pers. comm.), and eelgrass grew further north in the past (Chapter Four). Instead, the upper limit estuarine limit of eelgrass growth may be due to nutrient loading.

For example, eelgrass beds in the north end of the West Branch have more conspicuous algal epiphytes, and drift algae accumulates among shoots. Drift and attached algae were especially prevalent in bed WEWB1, and eelgrass is sparse here and other poorly flushed areas in the upper estuary, and cover less than 40% of the outlined areas. Light availability to eelgrass diminishes as one proceeds north into the estuary: eelgrass grows below 1.8 m MLW near the mouth, 1.2 m at Whites Flat, 0.9 m north of Great Flat, and less 0.6 m around Hicks Cove. There is much farmland in the drainage basin of this estuary, as well as homes along shore that may be contributing nutrients to this estuary, and may account for these trends.

All together, there was approximately 180 ha of eelgrass in the West Branch (adjusted for percent cover) in 1984. The East Branch has 60% greater subtidal area than the West Branch, but because eelgrass is largely absent from the top quarter of the estuary, eelgrass bed area, for production calculations, was conservatively estimated to be 100 ha.

Off Horseneck Beach and Gooseberry Pt., considerable wave action reduces water clarity and makes interpretation of photographs difficult. Eelgrass grows to 3.6 m MLW on the outer coast of Dartmouth, with

similar depth penetration, 400 ha of potential substrate on the outer coast of Westport. Eelgrass is not abundant nearshore because of high wave energy, but some eelgrass may grow among the boulders deeper offshore. For production calculations, 10% of this area was assumed to have eelgrass cover.

Dartmouth: Allens Pond to Round Hill (Figs. 5 + 6)

This map were based on 1975 and 1981 aerial surveys and several field visits in 1984 and 1985. Allens pond was not included in this study, but eelgrass was reported there by local residents.

This area has diverse habitats in which eelgrass grows. Eelgrass is abundant on the mud and sand bottom between the mouth of the Slocums and Little Rivers around Potomska Pt. The water is discernibly brown and turbid here during outgoing tides do to the discharge of the Slocums river which carries a high load of iron oxides. The shoots growing in this area are heavily epiphytized, perhaps due to the nutrient content of the river water. Because of the water turbidity and epiphyte growth, eelgrass grows only to 0.9 m MLW in a 4-6 m strip on either side of a 2.1 m MLW channel.

Eelgrass is very sparse in the Slocums River north of Potomska Point, and water transparency or nutrient loading may limit eelgrass distribution there as well. New seedlings were observed in this area during the summer of 1984, but they were heavily epiphytized and no perennial beds were found. Eelgrass also disappears abruptly at the 50 m south of the bridge at Little River, but this is probably due the

shallowness of the flood delta there. It was not determined whether eelgrass grows north of the Little River bridge.

In contrast, the bed by Barneys Joy (DABJ1) grows in a high energy, well flushed, coarse sand environment, to 1.2 m MLW. This bed was more robust and had greater biomass (shoot density > 400 m^{-2}, 190 g dry wt m^{-2} ; n=4, se=10).

South of the channel at Potomska Pt. is a large sand flat. Eelgrass may grow at the south-most deep edge of this feature, but no beds could be identified from either the photographs or field visits. Eelgrass beds visible on photographs of the north side of Deep Point the during early 1970's disappeared because of erosion in that area in 1978.

Offshore from Allens Pond and Barneys Joy, wave action is strong and submerged vegetation could not be discerned on photographs. The bottom is covered with large boulders, but it is likely some eelgrass grows there, although its extant is unknown.

Mishaum Pt. has a large boulder field to its west, and eelgrass is extensive here beginning at 0.6 m MLW among the rocks. Eelgrass may also grow along the southeastern and southwestern shores of Mishaum Pt., but this area was not field investigated and the sharp slope of the bottom makes interpretation of the photographs difficult.

The beds indicated in Salters Pt. Pond may be algae. Whether they are algae or eelgrass, the vegetation is less abundant in the 1981 photograph than the 1970's photographs. Outside of Salters Point Pond is a dense eelgrass bed in which a transect was run. Biomass was 160 g dry wt m^{-2}, density was 350 m^{-2}, and leaf canopy exceeds 1.2 m.

Epiphyte levels were high for a relatively well flushed area, and this may be do to the presence a sewage discharge pipe adjacent to the bed.

Immediately east of Salters Pt., vegetation was discernible on the 1981 photograph, but was not field verified, and may consist of rock covered algae as well. The beach west of Round Hill is sandy and eelgrass is absent nearshore except for bed RB1.

Round Hill Pt. is a high energy environment with large rocks and cobbles. Nonetheless, eelgrass is quite abundant below 2ft MLW between rocks and along stretches of sand. Eelgrass is abundant around Dumpling Rocks where sand accumulates and grows to 3.7 m MLW. Both here and the large bed DARH1 contain much rock and boulders and, only 50% eelgrass cover is assumed for production estimates. The eelgrass beds north of Round Hill also contain rock and algae, and the beds show dynamic changes in distribution between recent photographs.

Eelgrass continues north along the shore of Nonquit. These beds were mixed with rocks and algae, making their exact dimensions are unclear, although they appear to occupy a strip along shore, mostly less than <30 m wide. Many of the beds are too small to be identified from photographs.

Altogether there are 150 ha of substrate less than 3.6 m that were not mapped in this area, and for production estimates, 30 h of eelgrass is assumed to grow in these locales.

Apponagansett Bay, Dartmouth to New Bedford (Figs. 7 + 8)

The map of eelgrass distribution in this area were based on 1975, and 1981 photographs, and field visits in 1984 and 1985. This area has

had sizeable anthropogenic disturbances in the past, and both Apponagansett Bay and the New Bedford area have seen considerable decline of eelgrass during the last 15-25 y (Chapter 4).

In field visits in 1985, eelgrass extended midway between Nonquit and the Padanaram bridge on the Western shore. Similarly, eelgrass disappears in the outer harbor near Giffords Marina on the eastern shore. In 1985, no eelgrass was found north of the Padanaram bridge despite reports that it does grow there. In photographs taken prior to 1982, some eelgrass is present in the bay, but many of these beds apparently disappeared. Identification of photographs is difficult in some areas because of drift material, including the extreme north end of the Bay along the banks of the bay. This area was not field verified and it was assumed that this is drift algae or *Ruppia*.

The absence of eelgrass in the inner harbor appears to be due to increased light availability. For example, eelgrass grows south of the Marina in the outer bay and continues southward to Ricketsons Pt at the mouth of the harbor. Near the mouth of the Bay, eelgrass grows down to 2.5 m MLW, however, the maximum depth of growth decreases as one proceeds northward and rises to 1.2 m south of the marina, then disappears entirely. Epiphytic algae on eelgrass leaves increase conspicuously along this same transect. Prominent accumulations of *Gracillaria* and *Ulva* in the inner harbor further suggest that nutrient loading is high in this area. Boat activity may also be contributing lesser light availability to eelgrass (see chapter 4).

Along Ricketsons Pt., eelgrass occurs extensively amongst the large boulders and cobble, but only 50% cover was assumed for these

beds. Southwest of Ricketsons Pt., eelgrass may grow in deeper water, but could not be discerned on available photographs.

Small patches of eelgrass were found nearshore during dives in 1985 between the area immediately north of Ricketson Pt. and Clarks Cove. These beds were abundant nearest to Ricketson's point and gradually became less abundant to the north, and disappeared completely at Moshers Pt. No eelgrass could be found in the field or on photographs along any part of Clarks Cove.

Eelgrass is virtually absent from any part of the coast of New Bedford, although this was not true in the past. The only eelgrass found today in New Bedford is a small area on the southwest corner of Clarks Pt. Here eelgrass grows amongst a rock and boulder field at 0.3 m MLW and continues offshore to an unknown depth, but probably less than 0.9 m MLW due to low water transparency there. The New Bedford sewage outfall, which is conspicuous on aerial photographs, discharges 600 m from this bed.

Eelgrass is absent in Fairhaven along the Acushnet River shore and Fort Phoenix shores.

Fairhaven to Brant Island, Mattapoisett (Figs. 9 + 10)

This vegetation map was base on 1972, 1974, 1980, 1981 aerial surveys. Underwater and boat observations were conducted in 1984 and 1985 east of the mouth of New Bedford Inner Harbor, and south along the western shore of Sconticut Neck, at North Cove on West Island, and around Nasketucket Bay.

loading is high in this area. Boat activity may also be contributing lesser light availability to eelgrass (see chapter 4).

Along Ricketsons Pt., eelgrass occurs extensively amongst the large boulders and cobble, but only 50% cover was assumed for these beds. Southwest of Ricketsons Pt., eelgrass may grow in deeper water, but could not be discerned on available photographs.

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Eelgrass is absent in Fairhaven along the Acushnet River shore and Fort Phoenix shores.

Fairhaven to Brant Island, Mattapoisett (Figs. 9 + 10)

This vegetation map was base on 1972, 1974, 1980, 1981 aerial surveys. Underwater and boat observations were conducted in 1984 and

connecting Brant and Ram Islands. This is a high energy environment with a sandy bottom; the eelgrass coverage consisted of circular patches 2-10 m in diameter spread about 1 bed diameter apart in shallow areas. South of Ram Island the margin of the eelgrass was difficult to discern on available photographs and is partly based on bathymetry.

Brant Island Cove was not entered but appeared to contain some eelgrass in the 1981 photograph. Eelgrass may also grow around White Rock, but this area was not investigated. Small patches of vegetation between 2.4 and 3.6 m MLW in Nasketucket Bay may be unrecorded.

Mattapoisett Harbor and vicinity (Figs. 11 + 12)

This eelgrass map was based on 1978 and 1981 photographs, and except for the Brant Island-Ram Island local described in Map 4, no part of this area was examined in the field, although information was obtained from the Mattapoisett shellfish warden.

Mattapoisett Harbor is moderately developed alongshore and is subject to considerable boat traffic. Until recently, a sewage outfall had discharged in the harbor for many years. The slope of the shoreline is steep, and much of the bottom is below the limits of eelgrass growth. Eelgrass beds are easy to discern in most of this area from aerial photographs, except the inner portion of Mattapoisett Harbor. Here, poor water clarity, steep beach slope, and poor contrast between vegetation and substrate combine to make photograph interpretation difficult, and parts of the lower bed boundaries are estimated based on bathymetry.

Eelgrass beds north and east of Strawberry Pt. are distinct, but this is a high energy environment, and these beds show variability in shape on recent photographs, especially near shore. The vegetation indicated in Pine Island Pond may be composed mostly of algae and or *Ruppia*, and this area needs to be further study. Rocky ledges offshore and the mouth of the Mattapoisset River may also contain eelgrass populations.

Hiller Cove, Mattapoisett to Marion (Figs. 13 + 14)

Like the last area described, this vegetation map was based primarily on aerial photographs (1972, 1974, 1978 and 1981) and information from the shellfish warden. Only Bird Island and Butler Pt. were examined in the field.

Bird Island is surrounded by rock and boulder particularly on its south side and is a moderately high energy environment. Nonetheless eelgrass grows abundantly below the tidal wave action and is quite dense between the Island and Butler Pt, except on the sand bar connecting the two.

Blankenship and Planting Island Coves contain much algae and some *Ruppia*. Eelgrass is present here, but with low cover, and beds have been declining in recent years (G. Taft, pers. communication and chapter 4). In addition, drift algae have been accumulating here in recent years. Nutrient inputs from nearshore developments may be a factor in both these changes.

The north end of Sippican Harbor has poor water transparency and accumulated drift algae making bottom vegetation difficult to discern.

Some eelgrass is apparent south of Little Neck and Hammet Cove and along shores to the south.

Sippican Neck, Marion to Great Neck, Wareham (Figs. 15 + 16)

This map was based on 1975, 1978, and 1981 photographs and field observations were made in the Great Neck-Wareham River Area 1985.

Much of the offshore habitat in this area is within the depth range of eelgrass growth and eelgrass is abundant throughout the area. Bed WAGN1, one of the largest continuous beds in Buzzards Bay, was sampled in 1985. Eelgrass grew to 2.4 m, leaf canopy was 70 cm. Near the deeper edge of the bed *Codium* was abundant, attached to shell and stone, often covering 20% of the bottom. In this area there were large bare areas as well. The mean biomass here was 75 g dry wt m^{-2}, and shoot densities were exceed 200 m^{-2}. Other parts of the bed have higher densities and standing stocks. The sediment at the transect site was composed of 30% silt and clay, 20% sand, and the surface was covered with 1-2 cm gravel.

Eelgrass is abundant at the mouth of the Wareham River. Further upriver, water transparency declines, and periphyton and drift algae are increasingly abundant. Most of the vegetation drawn on this map was based on a 1981 survey. In 1985, the beds on the shore north of Swifts beach could not be found and may have disappeared. Drift algae is abundant here and may have replaced some of the beds. While eelgrass grow to 3.5 m off great neck, eelgrass grows to only to 1.0 m MLW north of Crescent Beach. The upper estuary limit of eelgrass distribution

appears to be near Crab Cove in 1981, but this vegetation could not be found by boat in the summer of 1985.

Along the Marion shore, eelgrass forms nearly a continuous subtidal band among rocks and boulders. Eelgrass is abundant in Marks Cove, around Cromset Neck, and into the Weweantic river. The upper extant of eelgrass in the Weweantic was not determined, but at least extends to the bridge near its mouth. The beds in Marks Cove were not sampled, but eelgrass was more continuous and denser than on the shoal south of Long Beach Point (bed WAGN1).

Eelgrass is very abundant around the rocky shallows that make up Little Bird Island. The beds are densest adjacent to the Island and on the sand spit that meanders northwest of the Island. Sparser cover continues to the south and west. The deeper areas to the north and east of the island do not support eelgrass. The beds around Great Hill Point contain considerable algal covered rock fields.

Great Neck Wareham to Pocasset, Bourne (Figs. 17 + 18)

The map of eelgrass beds between Great Neck and Pocasset were based on aerial photographs, taken in 1971, 1975, 1974, and 1981 and field surveys in 1985 and 1986 around Buttermilk Bay and areas south to the Canal.

This region is dominated by shallow, protected embayments, with good water circulation, in part due to water exchange through the Cape Cod Canal. Most of the shallow coves have extensive eelgrass cover making this region and the adjacent south shore of Great Neck have the highest total coverage of any area in this study.

Buttermilk and Little Buttermilk Bays are typical of the shallow embayments in this area, and eelgrass grows densely in each (<1.5 m MLW and <1.2 m MLW respectively). Dense beds also occur in Onset Bay and around Great Neck and Point Independence. The vegetation indicated in the upper reaches of some of these coves, for example, bed BOTI5 at Toby's Island, bed BOAP2 at Mashnee Island, as well as the beds northwest of Shell Pt., and in Broad Cove probably contain considerable amounts of drift algae and possibly *Ruppia*.

Among the interesting features in this region are the eelgrass beds surviving on the Canal flood deltas south of Taylor Pt. and Mashnee Island. These beds occupy a region of high current velocity and have a very distinct striated pattern.

Between Little Bird Island (Map 7A) and Stony Point, a shallow shelf covers hundreds of hectares with a depth of 1.8 to 3.0 m; much of it covered with eelgrass, forming some of the largest eelgrass beds in Buzzards Bay. Water transparency is better here than at Longbeach because water clarity improves with increasing distance from the Wareham River toward the canal, and eelgrass grows to at least 3.0 m. Like the Longbeach Point shoal, this area probably contains considerable volumes of *Codium* as well. Because a large percentage of bed area grows near the depth limit of *Zostera* growth, any decline in water transparency will result in loss of large areas of eelgrass, making this an ecologically sensitive area.

On the shore east of the entrance to Little Harbor, eelgrass grows in the troughs of sand waves, creating a distinct banded pattern

observable on photographs. These beds show considerable movement between photographs.

The lower limit of eelgrass is was difficult to delineate on the photographs along the west side of Stony Point, Mashnee Island, and the West Side of Toby Island and are partly approximated based on bathymetry. Eelgrass grows along the margins of the Cape Cod Canal, but these were not included in production estimates.

This part of Buzzards Bay has become increasingly developed and urbanized, and water quality has declines have been reported in some areas such as shellfish bed closures in the Wareham River and Buttermilk Bays due to elevated coliforms. In Buttermilk Bay near inputs of nutrient sources, eelgrass grows to lesser depths or may be absent, and periphyton abundance is high (Costa, 1988, Costa and Valiela, in prep.).

Bourne: Wings Neck to Megansett (Figs. 19 + 20)

Maps of eelgrass abundance in Bourne, south of Wings Neck were based primarily on 1975, and 1981 aerial photographs and reports. No satisfactory photograph coverage was obtained west of Scraggy Neck.

Zostera is abundant in this network of shallow protected harbors. In low energy areas such as Red Brook Harbor and Wings cove, eelgrass is dense and continuous. On exposed parts of Scraggy Neck and Wings Neck, eelgrass beds nearshore are dominated by algae covered rock and boulder. The western tip of Scraggy Neck could not be interpreted clearly, but eelgrass appears abundant beginning at the edge of the boulder fields nearshore, and extend to the ledges a kilometer offshore. The eelgrass in this area appears to grow to at least 4.5 m. Even if rock and algae

covered 50% of the bottom, there still may be 35 ha of unmapped eelgrass vegetation in this area. Similarly, eelgrass may grow on the rocky platform north of Scraggy Neck, but is not indicated on the map.

Megansett Harbor is a shallow, high energy embayment, with sandy sediment and abundant eelgrass. Typical of this type of environment, eelgrass beds contain considerable bare patches where eelgrass was removed by storms or wave scour. Many of these beds also have distinct banding appearance because much of the habitat is too shallow, and eelgrass can survive only in the troughs of sand waves.

The periphery of this harbor has a gradual slope, but the bathymetry drops off sharply near the center of the bay. Eelgrass grows to 5.4 m here and bed FAMH26 fills all but the center of this basin. Potentially, some of this apparent "growth" is drift material, but this depth is consistent with maximum vegetation depth southwest of Scraggy Neck and east of Great Sippiwisett Marsh (Fig 18). Some of these deep beds probably contain considerable algae covered rock fields, and the maximum depth of growth of these beds needs further study.

Eelgrass is distinct on the sand bars surrounding the south end of Stony Point Dike. The Squeteague Harbor beds probably contain sizable amount of drift algae or *Ruppia*. The broad southern lobe of the canal ebb delta covers 120 ha at 2.4-3.3 m MLW 500 m north of Wings Neck. The shallow part of the delta is covered with eelgrass (also Figure 18), but it is unclear if this deeper lobe is vegetated.

Falmouth: Megansett to West Falmouth Harbor (Figs. 21 + 22)

These maps were based on from 1972, 1975, 1980, 1981 aerial surveys. The distribution of eelgrass in West Falmouth Harbor was based on a 1979 low altitude survey and maps by Buchsbaum (1985).

Eelgrass is absent from along Silver Beach which may be due to the strong wave action and longshore transport apparent on photographs. Water clarity is good in this part of Buzzards Bay because eelgrass grows to 4.5 m MLW on most of the outer coast.

Accumulated drift material and *Ruppia* in West Falmouth Harbor make interpretation of aerial photographs difficult, especially in upper estuarine ares like Harbor Head. To adjust for algal cover, eelgrass cover was estimated as 50% of vegetated habitat area.

The deeper edge of eelgrass off Chappaquoit Pt. and the Falmouth Cliffs follow the 3.6 to 4.5 m contour.

Falmouth: Chappaquoit Point to Gunning Point (Figs. 23 + 24)

Aerial surveys from 1975, 1978, and 1981 were used to make this map. Field observations were made near Great Sippewisset Marsh.

This is a moderate energy environment with sand and rock covered shores. In addition. numerous peat reefs occur nearshore along both Little and Great Sippewisset Marshes. The deep beds offshore visible on photographs (to 4.2 m MLW) are consistent with bathymetry but may include rock fields. The percent cover of eelgrass beds in these and other rocky areas like Hamlin and Gunning Points (beds FAGU3, FAHP1, FAHP2) were reduced by 30% cover to account for rock and cobble fields.

No eelgrass was found in either Great or Little Sippewisset Marshes, but some *Ruppia* was reported in Quahog Pond.

Falmouth: Woods Hole Area (Figs. 25 + 26)

The map of eelgrass in the Woods Hole area was based primarily on a 1975 aerial survey supplemented by 1971, 1978, and 1981 aerial surveys and numerous field observations between 1981-1987. Biomass collections, productivity measurements, or both were made in Great Harbor, south of Uncatena, the East side of Juniper Pt., The Knob, west of Penzance Point, and along Quisset Beach.

This region offers diverse habitats for eelgrass growth, and depth limits of growth range from 3.6 to 6.0 m MLW. For example, some areas, such as the south side of Ram Island and the passages and harbors around Nonamesset, Uncatena, and Naushon Island (not shown), are protected from wave scouring and storms, but have a moderate current flow. The sediments are often composed of fine anoxic mud and silt, especially within the eelgrass beds. The combination of good water circulation and this type of sediment often results in the most luxurious beds in the region, with canopy height exceeding 1.5 m, and above ground biomass greater than 250 g dry wt m^{-2}.

This area coincides with a glacial moraine, and large rock and boulder fields are typical in this area, especially within the Hole and at exposed points. At MLW, many of these algae covered boulder fields are prominent at or just below the waters surface. Eelgrass is found in these areas generally below 0.9 m MLW where there are patches of sand, and more continuous beds are found to 5.5 m MLW. Some of these beds,

such GH10 and PP1, are extensive. Percent cover of eelgrass was adjusted for rock and algal cover in some areas.

The area east of Nobska Pt. was not included in the area summary of eelgrass in Buzzards Bay. This is high current velocity environment with a coarse sand and gravel bottom, little drift algae, and eelgrass growth to 6.0 m MLW in the clear water here.

Elizabeth Islands

The distribution of eelgrass on the Elizabeth Islands was not mapped, but eelgrass bed area was estimated to calculate total eelgrass production in Buzzards Bay. Eelgrass bed area was estimated from potential substrate area and eelgrass bed-substrate ratios (c.f. Chapter 1) and assumptions made from aerial photographs and field observations in several areas.

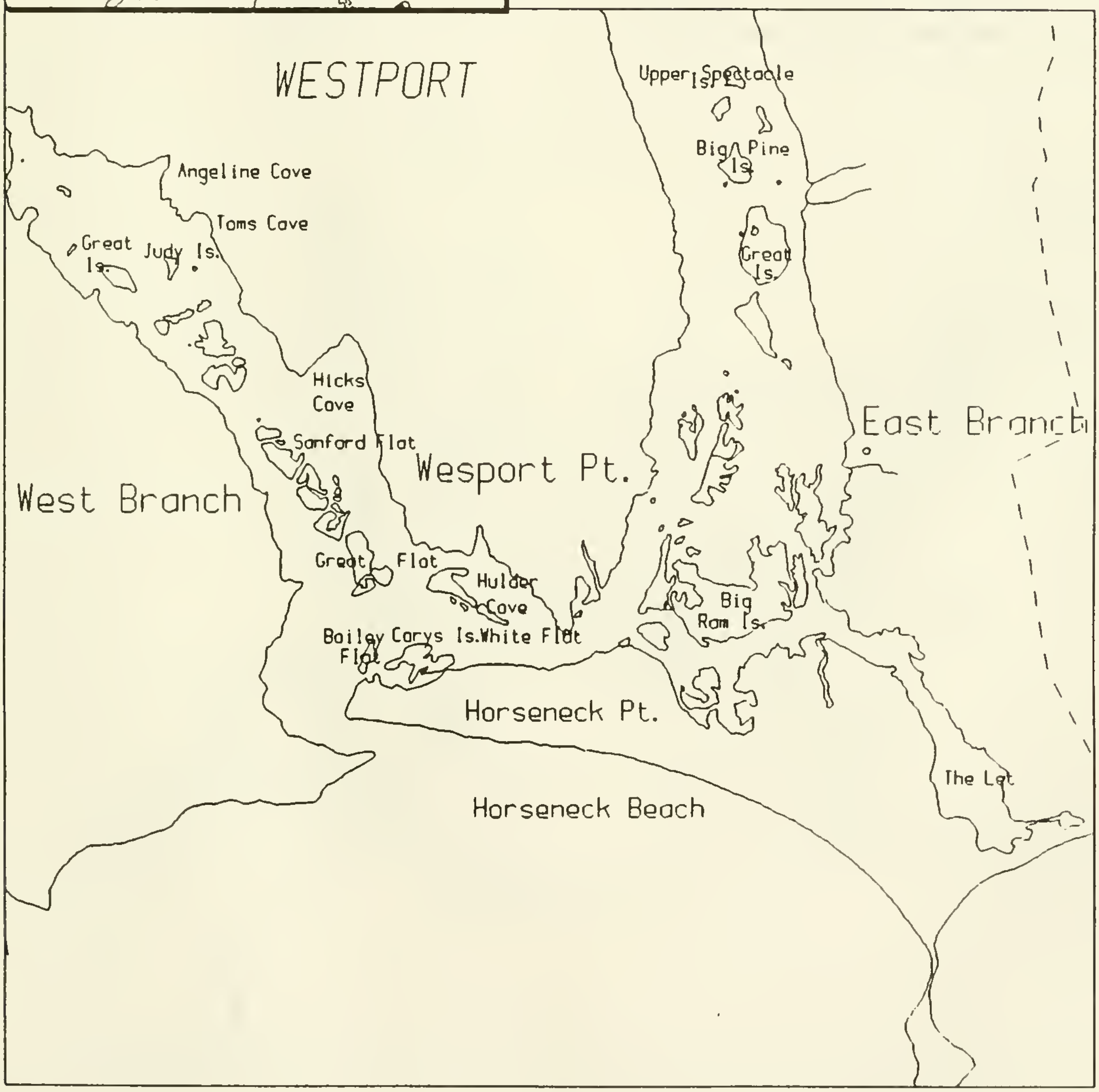
The islands are composed of diverse habitats. In protected coves, eelgrass grows in the intertidal to 2 m. Most of the shores facing Buzzards Bay however, are high energy, rocky environments, and eelgrass usually does not grow above 1.0 m MLW because of wave scour. Eelgrass grows deeper around the Islands than along the mainland part of Buzzards Bay because water transparency is better: on the outer coast eelgrass was observed at 6.0 m on the northeast end of the chain, and divers reported eelgrass growing in excess of 10 m on outer portions of the Island chain.

Even though eelgrass grows deeper in the Elizabeth Islands than other parts of Buzzards Bay, it is less abundant here because the beaches have very steep slopes, and large portions of potential

substrate area are covered by rocks and boulders from glacial deposition or sandy shoals. For example, the area of substrate less than 5.4 m (18 ft contour) around the is 1300 ha, compared to 8500 ha less than 3.6 m along the mainland of Buzzards Bay. If the mean substrate eelgrass ratio is 2.4 like other parts of the Bay (Table 3 in Chapter 1), eelgrass habitat area equals 540 ha in the Elizabeth Islands. To account for rock and cobble bottom and wave disturbance, only 50% of the area was estimated to contain eelgrass (vs 67% for other parts of Buzzards Bay, Table 2 in Chapter 1). Given these assumptions, eelgrass bed area along the Buzzards Bay shore of the Elizabeth Islands is 270 ha.

Figure 1. Map of Westport showing site names.

1000 m



MAP COORDINATES = 323 331 594.5 602.5

Figure 2. Map of Westport showing eelgrass beds.

1000 m

MAP COORDINATES = 323 331 594.5 602.5

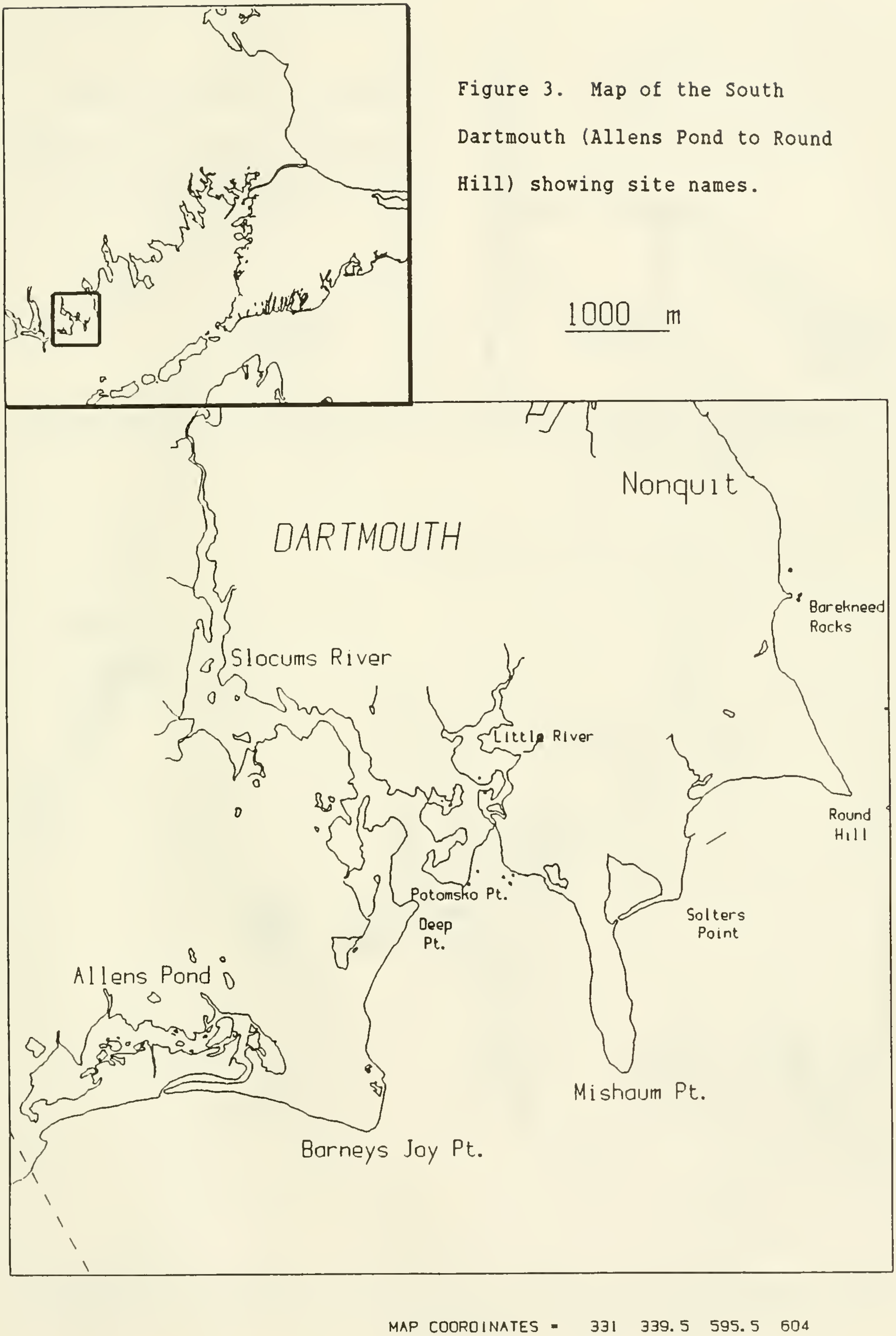


Figure 3. Map of the South Dartmouth (Allens Pond to Round Hill) showing site names.

Figure 4. Map of the South Dartmouth (Allens Pond to Round Hill) showing eelgrass beds.

1000 m

MAP COORDINATES = 331 339.5 595.5 604

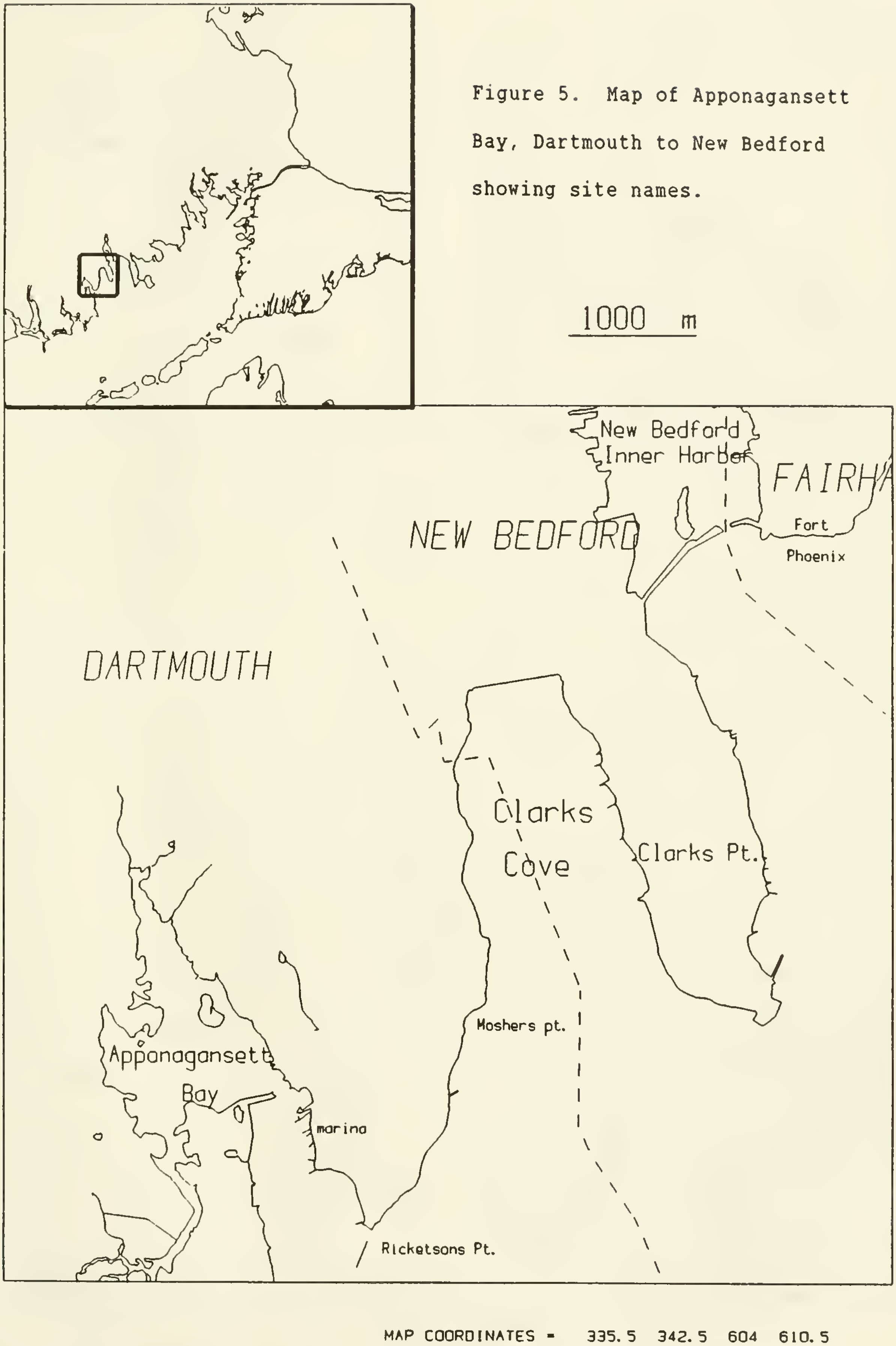
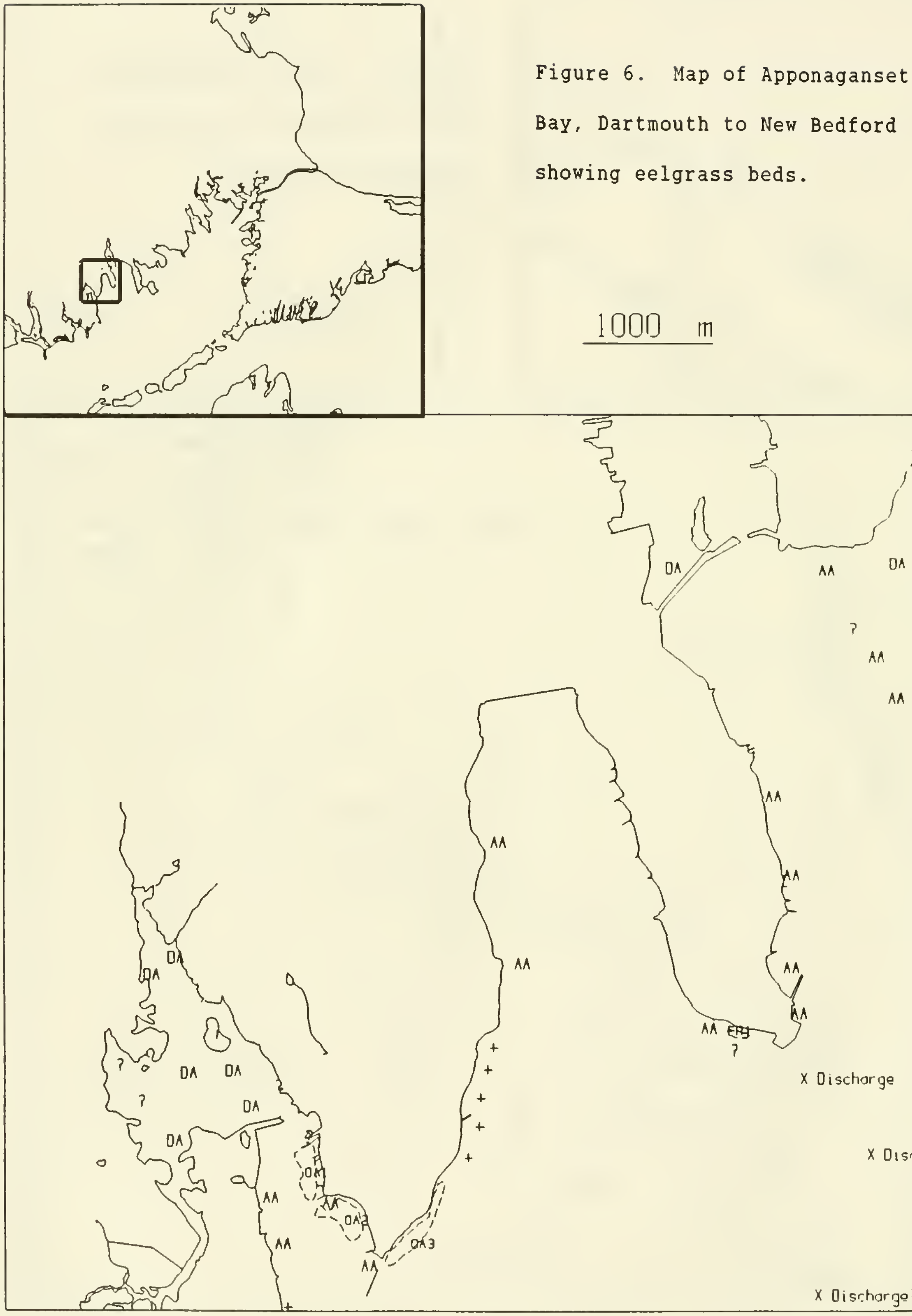


Figure 5. Map of Apponagansett Bay, Dartmouth to New Bedford showing site names.

Figure 6. Map of Apponagansett Bay, Dartmouth to New Bedford showing eelgrass beds.



MAP COORDINATES = 335.5 342.5 604 610.5

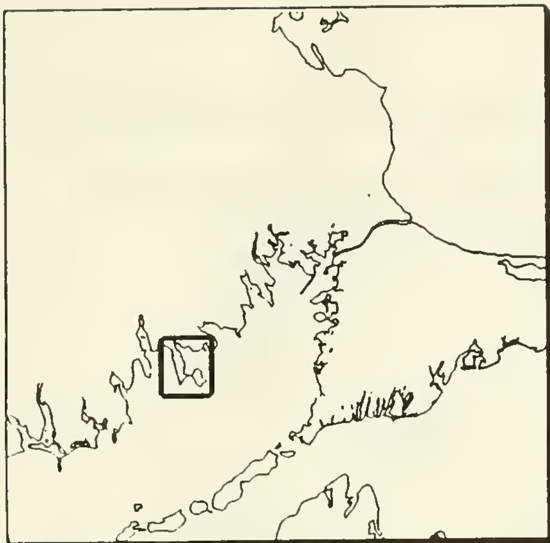
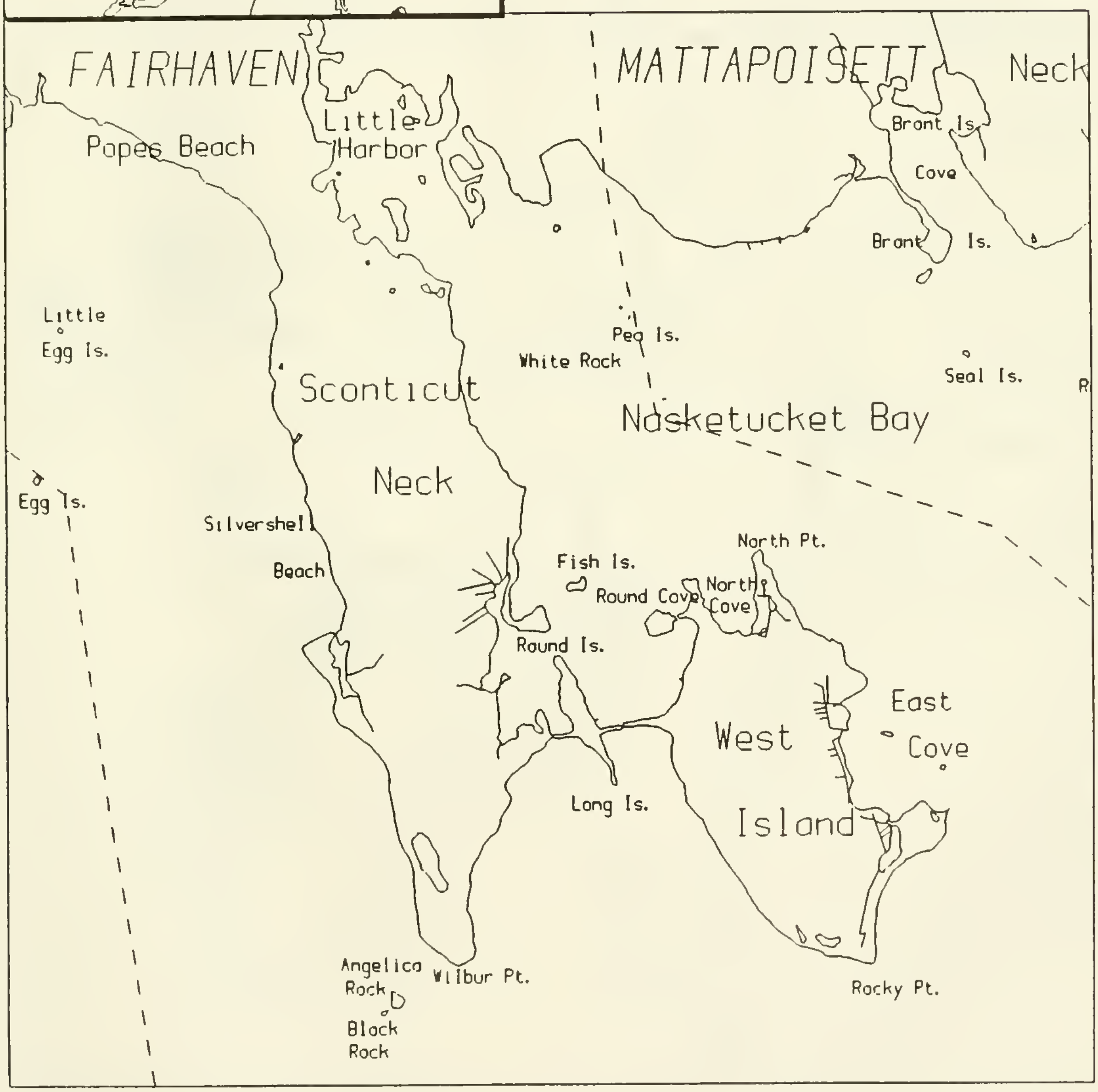


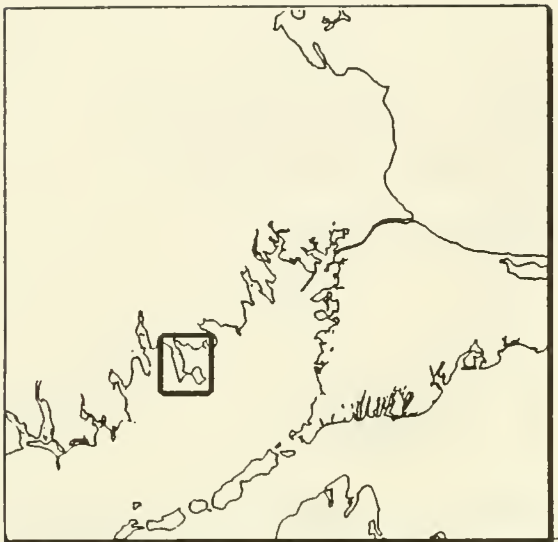
Figure 7. Map of Fairhaven to Brant Island, Mattapoisett showing site names.

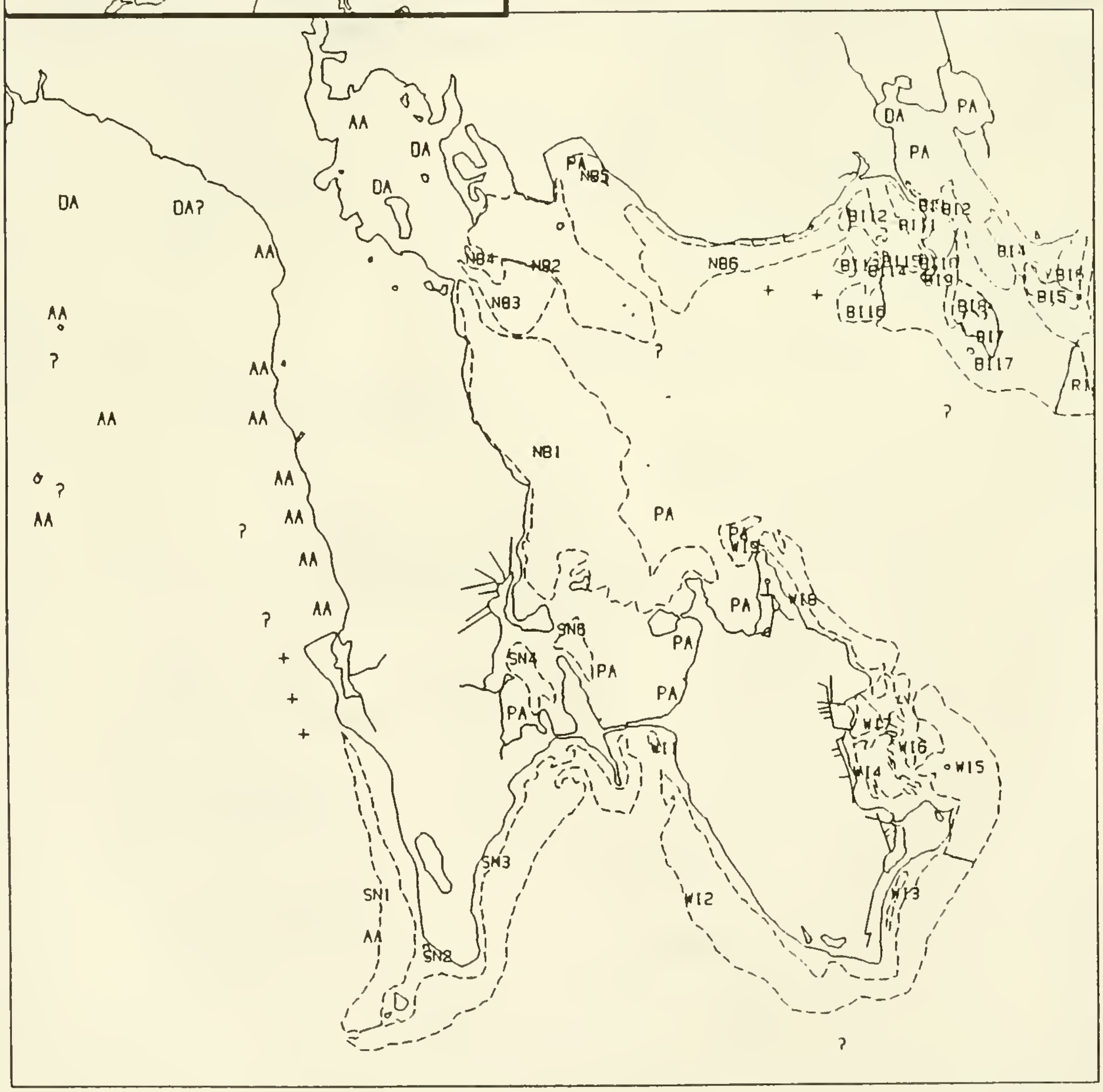
1000 m



MAP COORDINATES = 342.5 349.5 604 611

Figure 8. Map of Fairhaven to Brant Island, Mattapoisett showing eelgrass beds.





MAP COORDINATES = 342.5 349.5 604 611

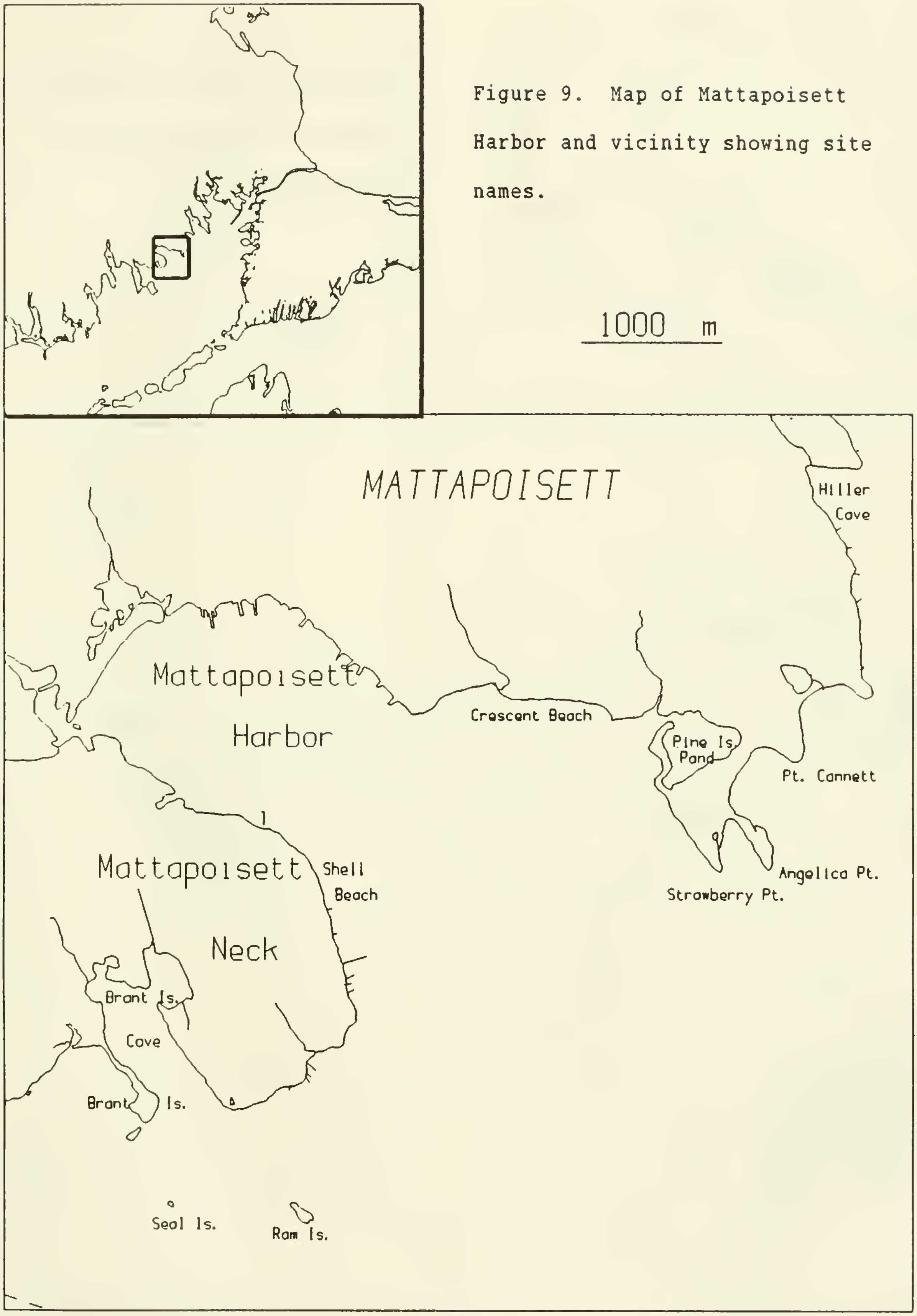
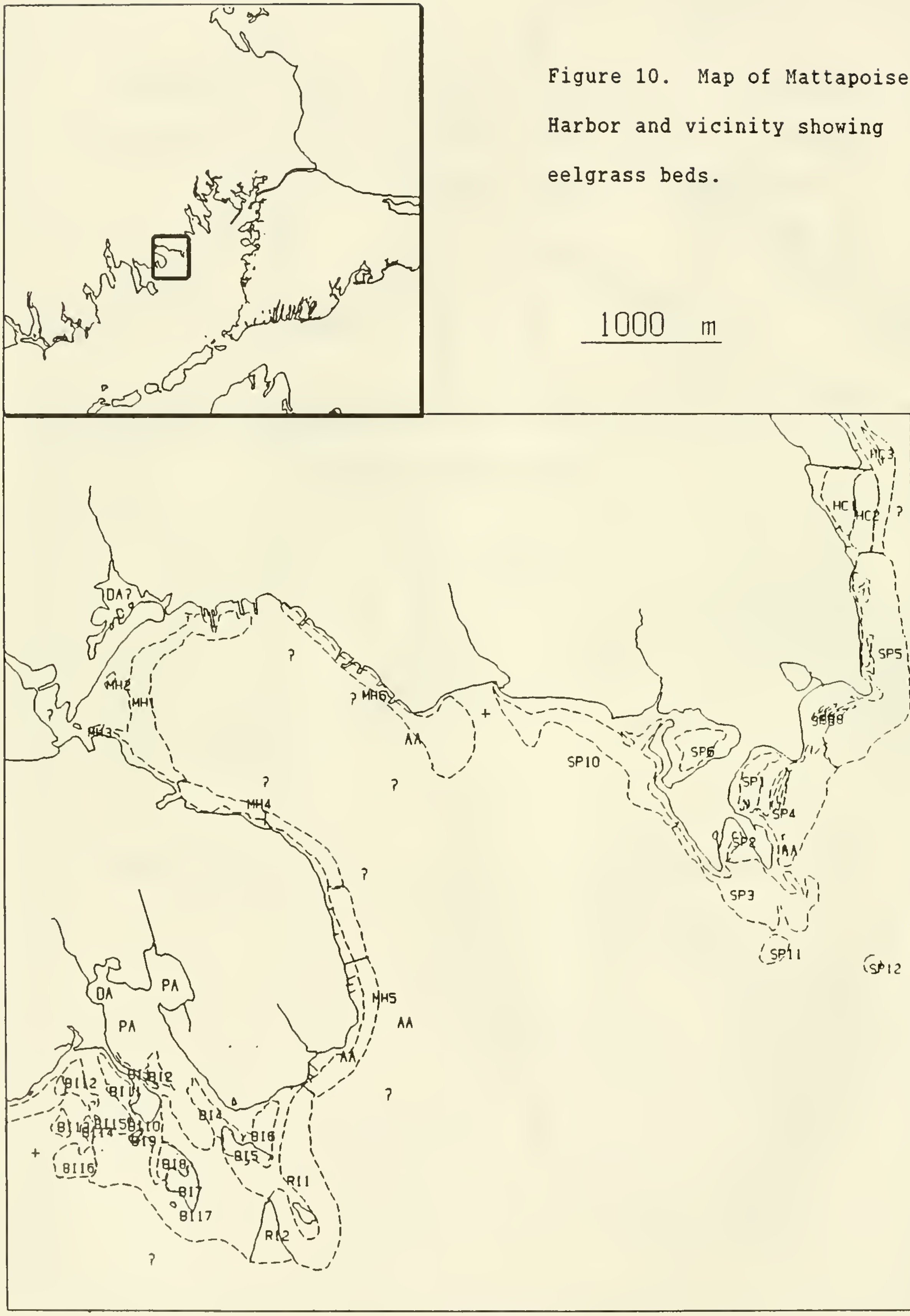


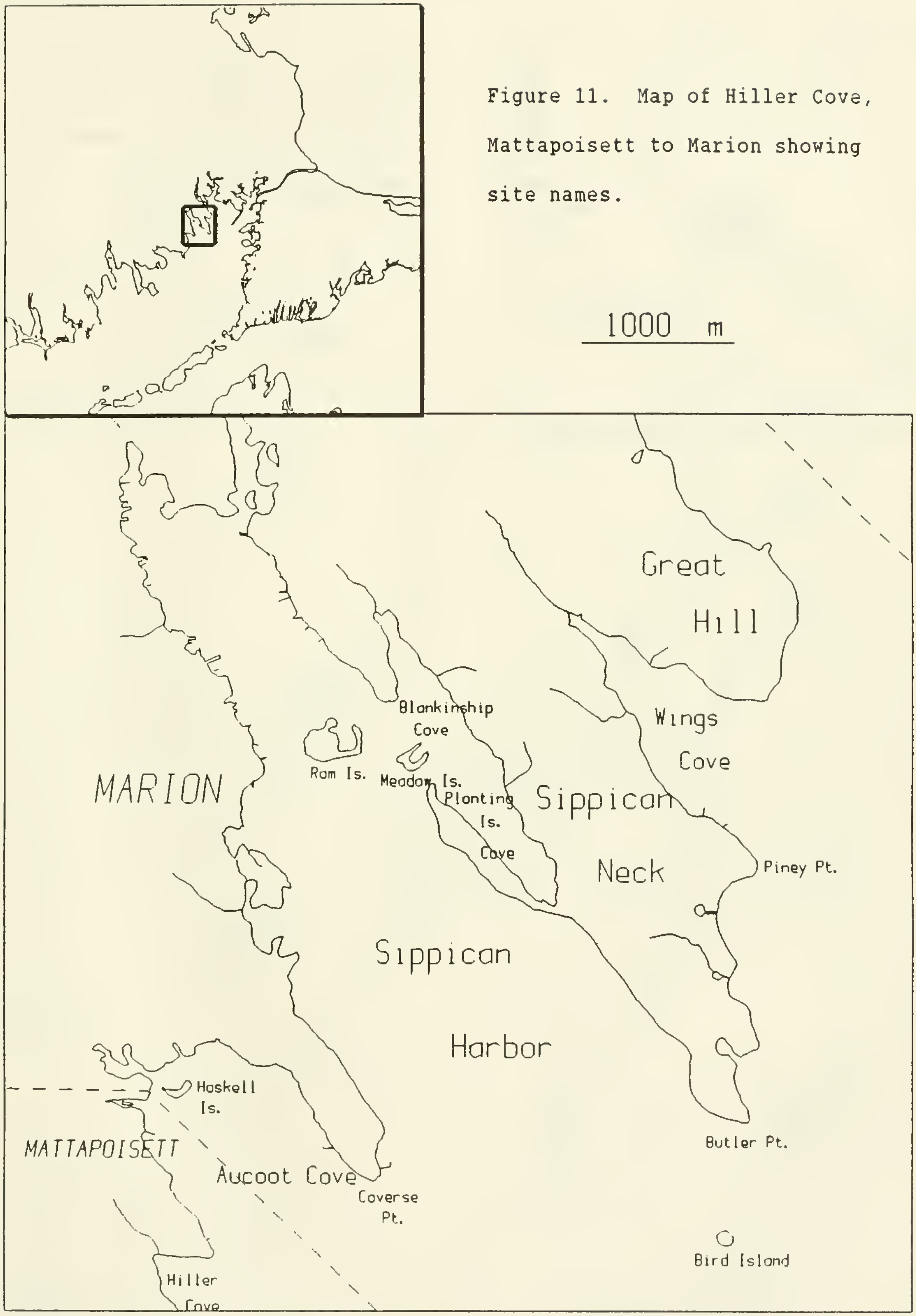
Figure 9. Map of Mattapoisett Harbor and vicinity showing site names.

Figure 10. Map of Mattapoisett Harbor and vicinity showing eelgrass beds.



MAP COORDINATES = 347.5 354 608 614.5

Figure 11. Map of Hiller Cove, Mattapoisett to Marion showing site names.



MAP COORDINATES = 352.25 358.25 613.75 619.75

Figure 12. Map of Hiller Cove, Mattapoisett to Marion showing eelgrass beds.

1000 m

MAP COORDINATES = 352.25 358.25 613.75 619.75

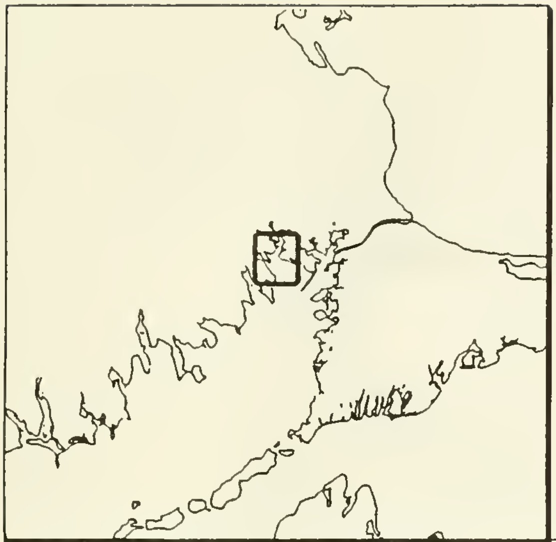
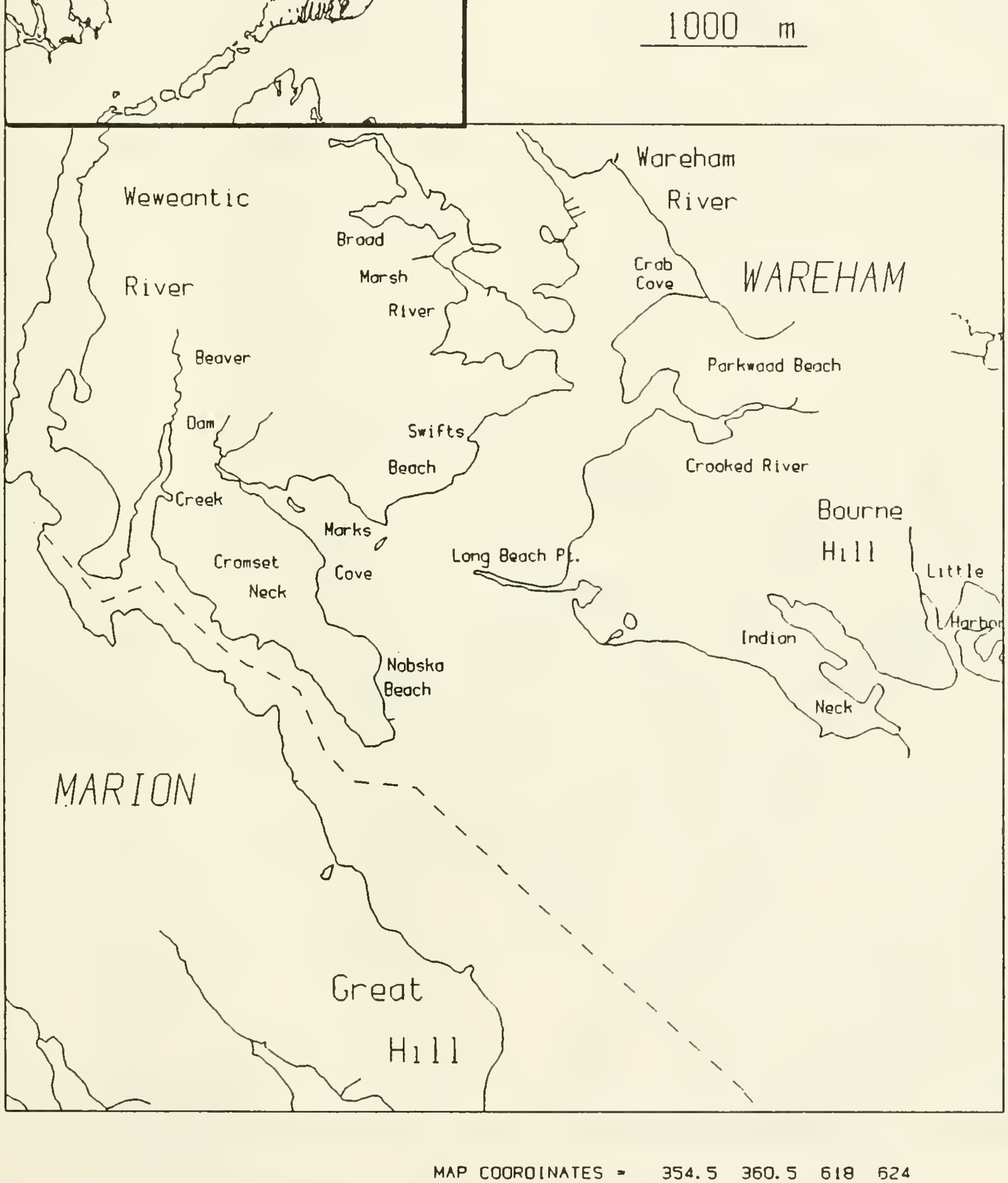


Figure 13. Map of Sippican Neck, Marion to Great Neck, Wareham showing site names.



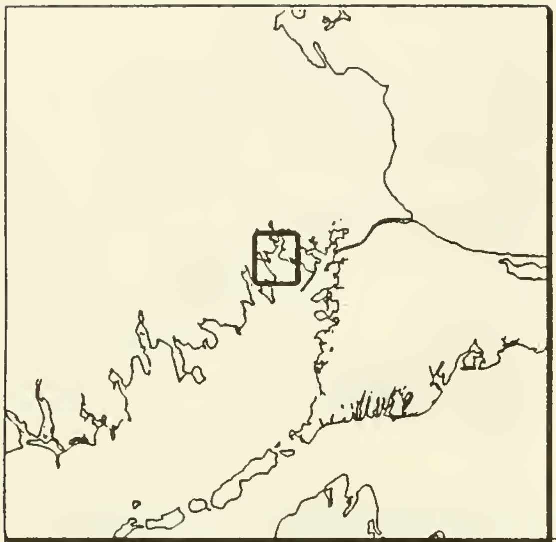


Figure 14. Map of Sippican Neck, Marion to Great Neck, Wareham showing eelgrass beds.

1000 m

MAP COORDINATES = 354.5 360.5 618 624

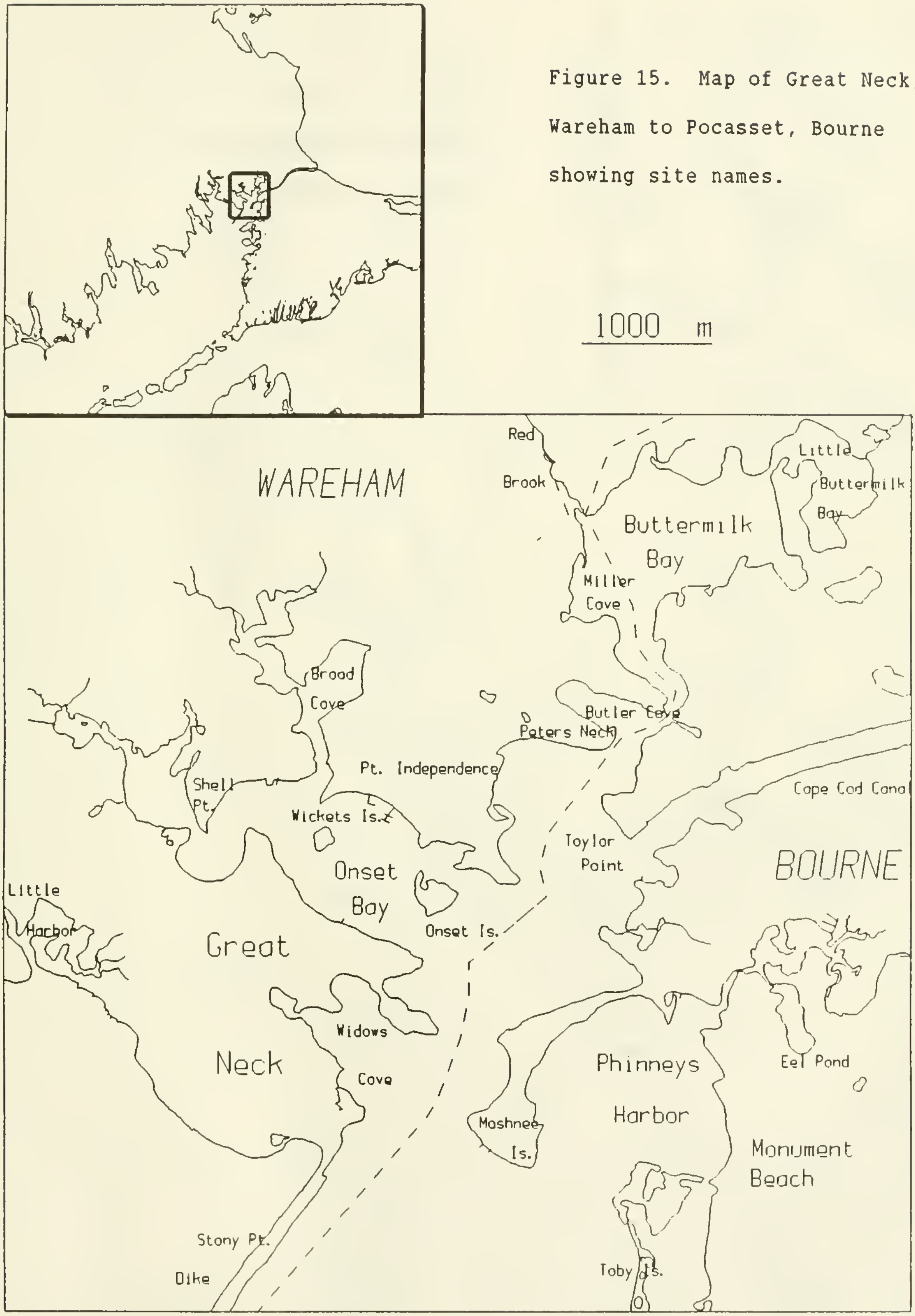


Figure 15. Map of Great Neck, Wareham to Pocasset, Bourne showing site names.

MAP COORDINATES = 360 367 618 625

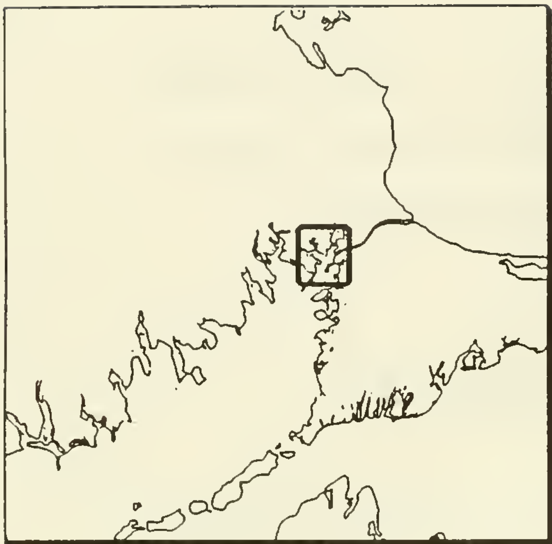


Figure 16. Map of Great Neck, Wareham to Pocasset, Bourne showing eelgrass beds.

1000 m

MAP COORDINATES = 360 367 618 625

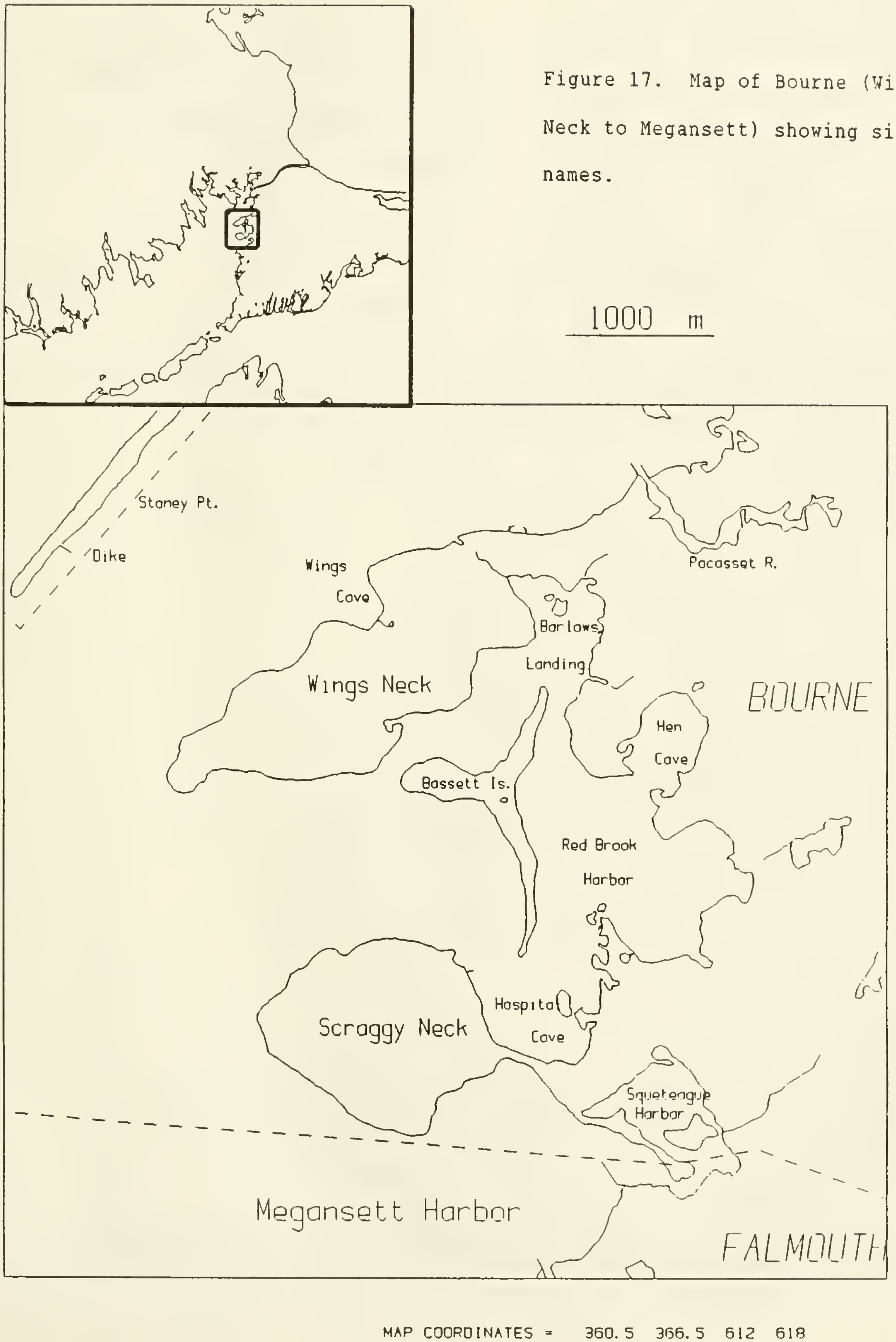


Figure 17. Map of Bourne (Wings Neck to Megansett) showing site names.

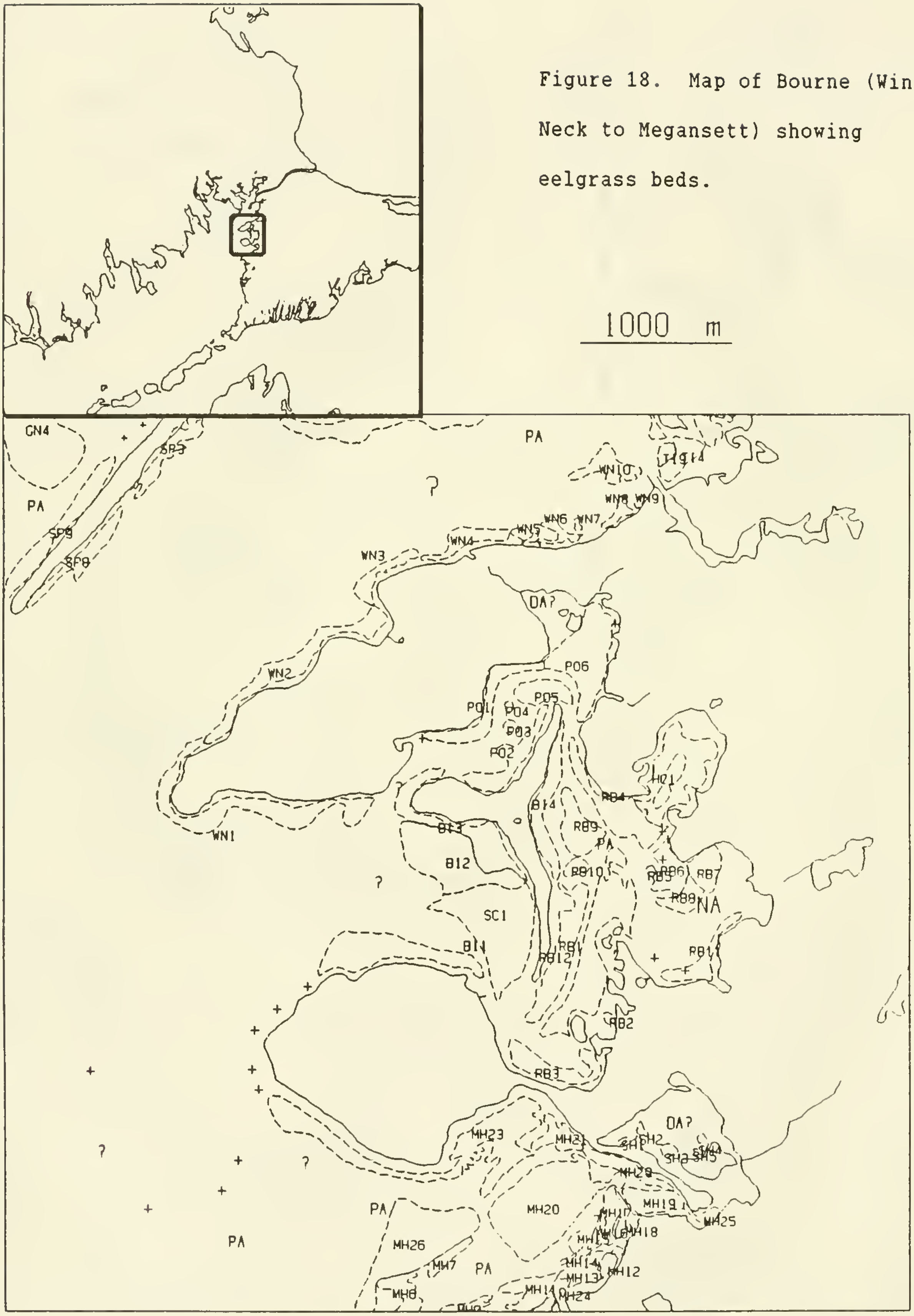


Figure 18. Map of Bourne (Wings Neck to Megansett) showing eelgrass beds.

MAP COORDINATES = 360.5 366.5 612 618

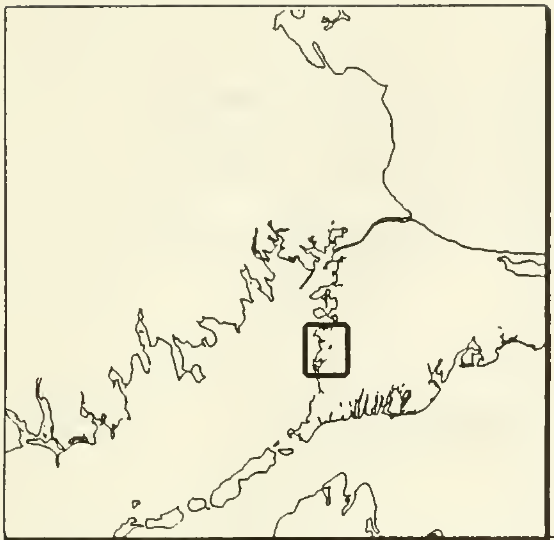
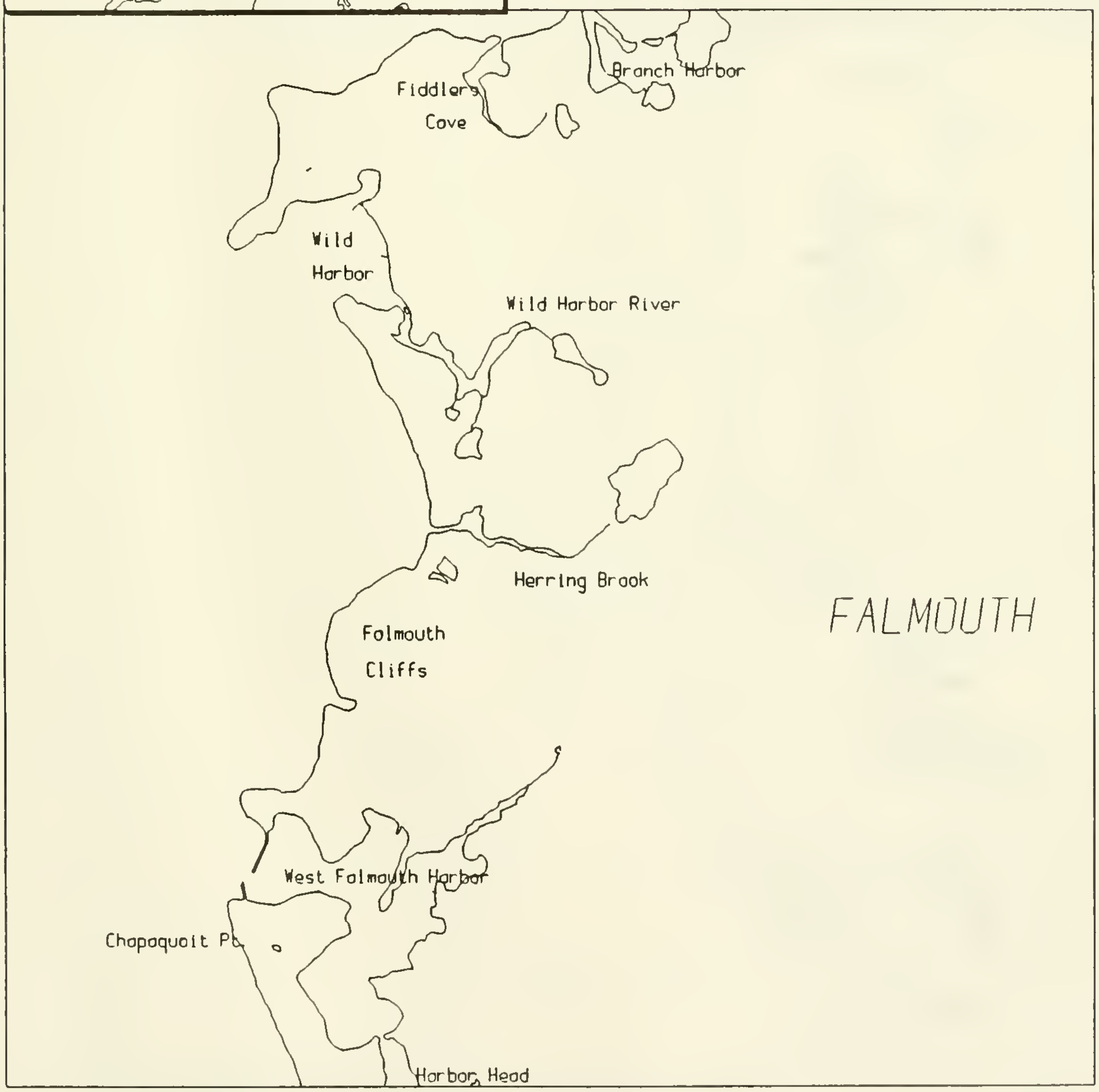


Figure 19. Map of Falmouth (Megansett to West Falmouth Harbor) showing site names.

1000 m



MAP COORDINATES = 361 367 606 612

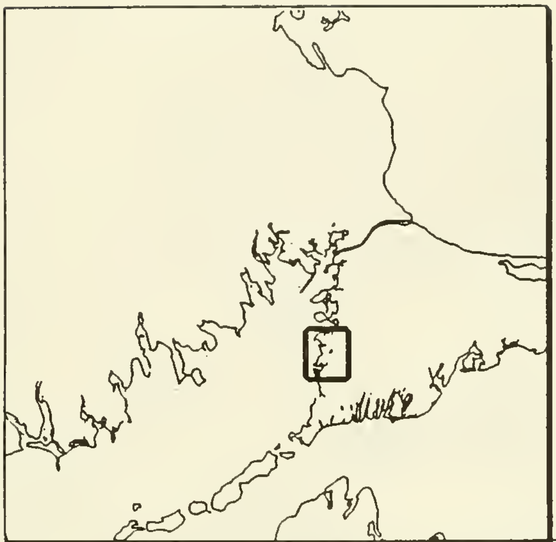


Figure 20. Map of Falmouth (Megansett to West Falmouth Harbor) showing eelgrass beds.

MAP COORDINATES = 361 367 606 612

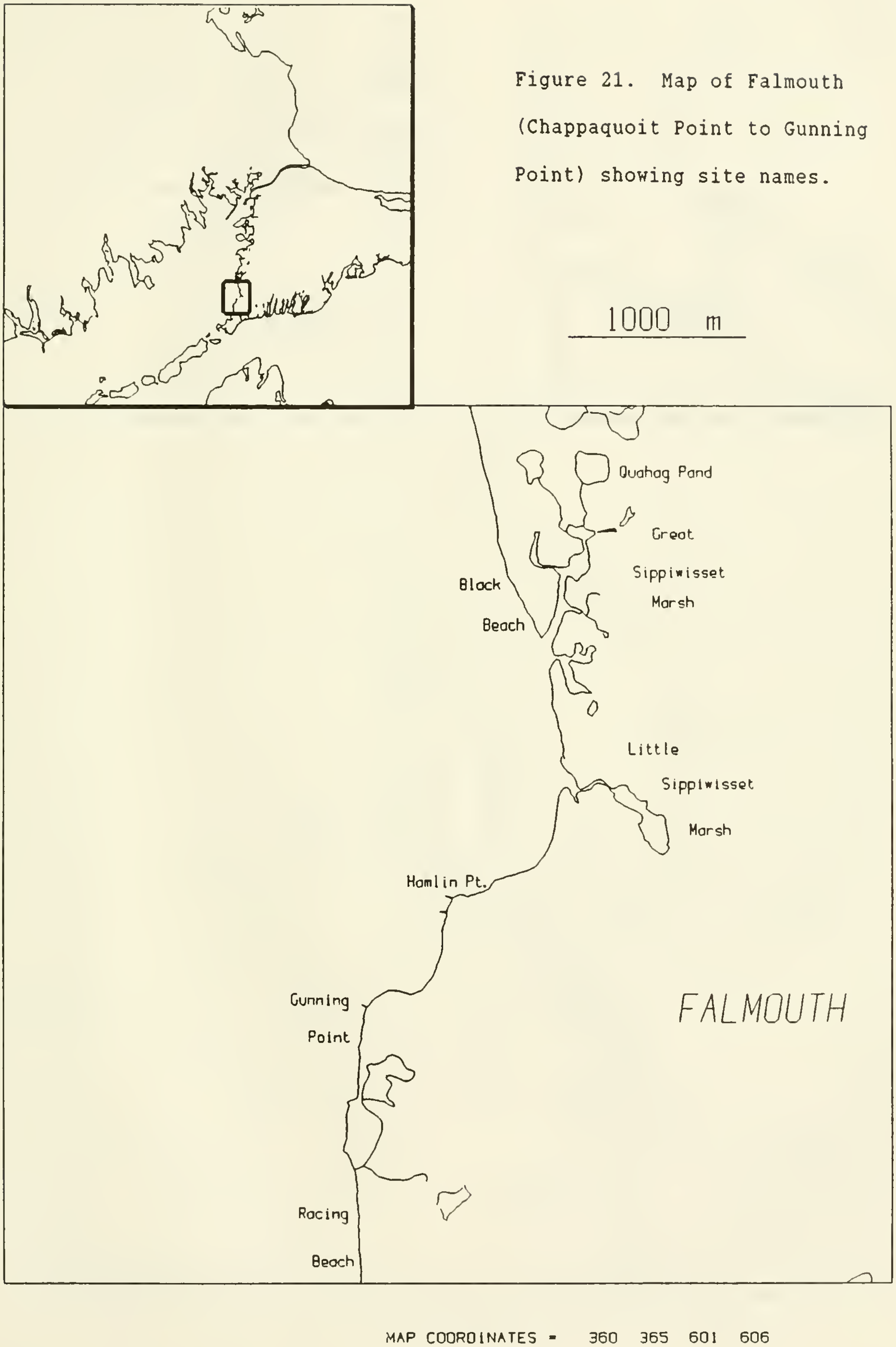


Figure 21. Map of Falmouth (Chappaquoit Point to Gunning Point) showing site names.

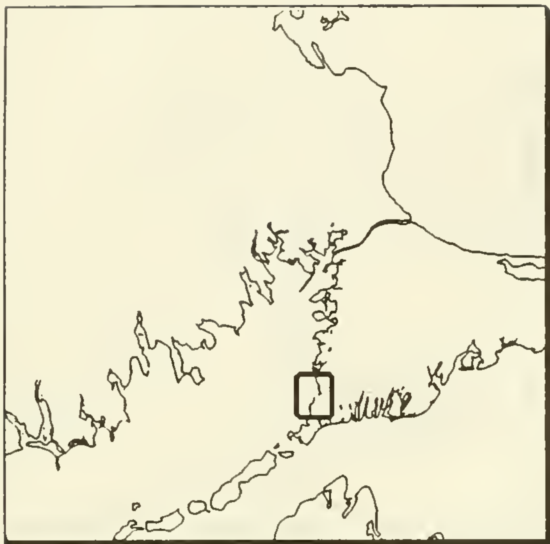
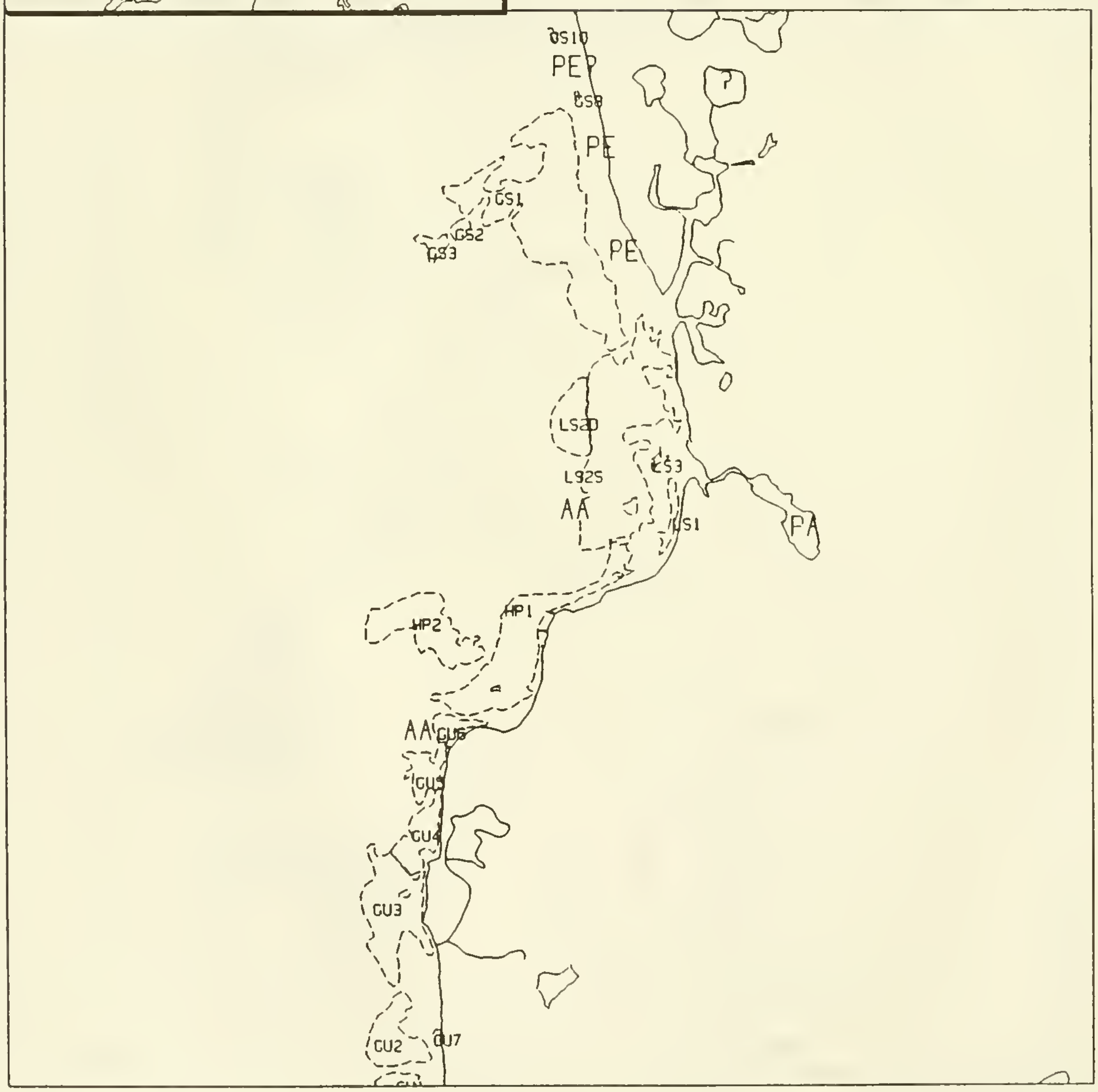


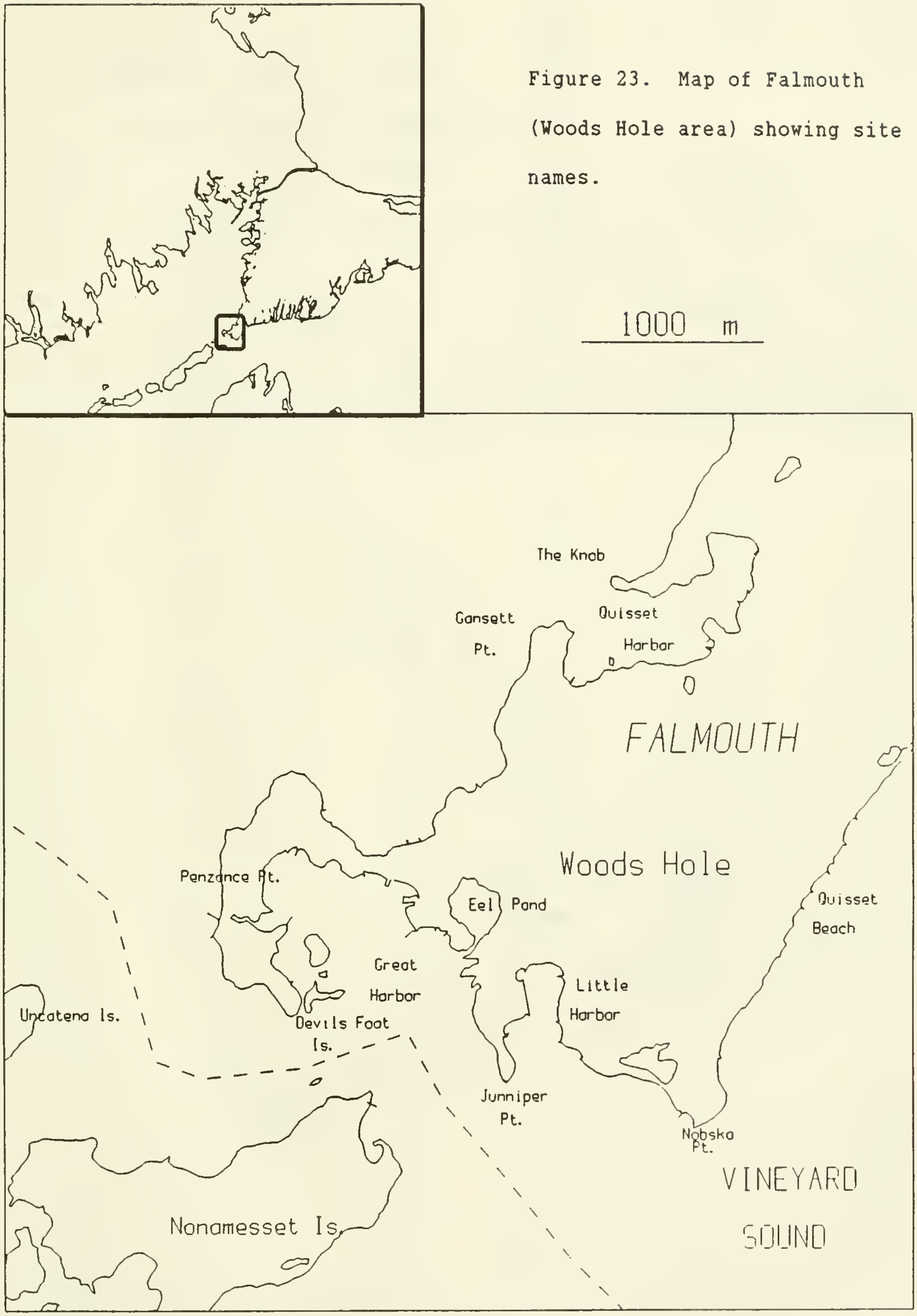
Figure 22. Map of Falmouth (Chappaquoit Point to Gunning Point) showing eelgrass beds.

1000 m



MAP COORDINATES = 360 365 601 606

Figure 23. Map of Falmouth (Woods Hole area) showing site names.



MAP COORDINATES = 358 363 595 601

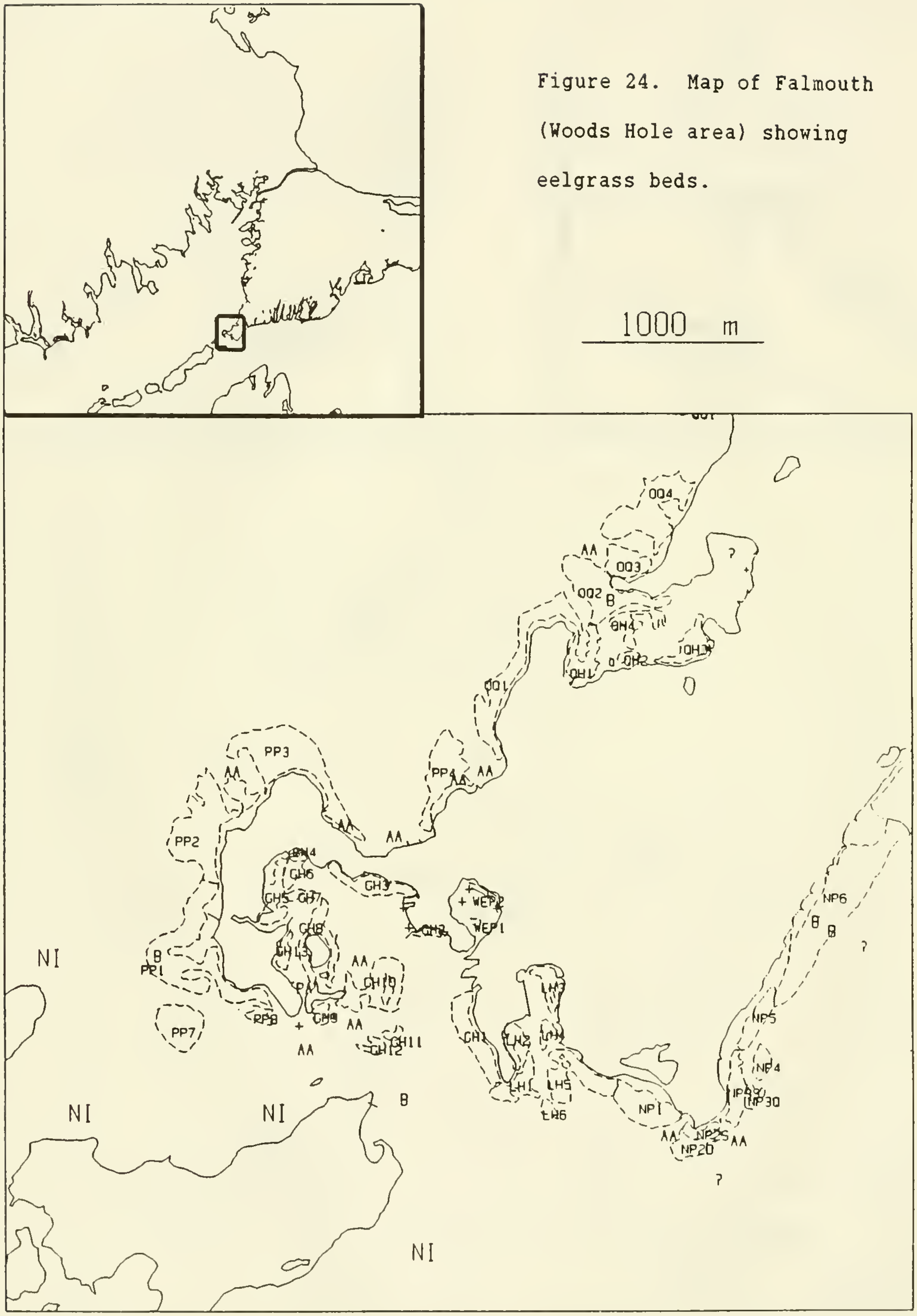


Figure 24. Map of Falmouth (Woods Hole area) showing eelgrass beds.

MAP COORDINATES = 358 363 596 601

Appendix III

Alphabetized listing of mapped eelgrass beds by town.

(Note: On the maps, the first two letters of the bed name (town ID) are omitted. All areas are in hectares).

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
Bourne beds				BOMH23	29.1	85	24.75
BOAP1	5.9	85	4.99	BOMH29	4.4	75	3.30
BOAP2	2.8	50	1.41	BOMI1	5.5	70	3.86
BOBB1	17.9	70	12.51	BOMI1D	4.6	60	2.74
BOBB10	2.4	35	0.85	BOMI2	7.3	80	5.80
BOBB11	3.3	40	1.31	BOMI3	10.3	70	7.22
BOBB12	1.5	40	0.60	BOMI4	14.0	95	13.28
BOBB13	2.4	30	0.72	BOMI5	4.9	60	2.93
BOBB14	3.3	85	2.77	BOPH1	22.0	95	20.87
BOBB16	1.1	70	0.77	BOPH2	17.7	85	15.01
BOBB17	0.4	50	0.18	BOPH6	1.8	35	0.63
BOBB18	0.1	50	0.04	BOPH7	6.1	40	2.44
BOBB2	14.7	20	2.94	BOPI1	7.1	40	2.85
BOBB4	1.8	60	1.10	BOPI6	5.6	80	4.49
BOBB5	2.7	10	0.27	BOPO1	8.0	80	6.36
BOBB6	2.0	50	0.99	BOPO2	7.5	80	6.01
BOBB7	4.0	65	2.60	BOPO3	0.7	80	0.58
BOBB8	1.3	75	0.94	BOPO4	0.3	75	0.26
BOBB9	3.5	70	2.45	BOPO5	4.8	75	3.59
BOBI1	26.9	85	22.90	BOPO6	17.0	45	7.65
BOBI2	19.9	65	12.93	BORB1	21.7	80	17.38
BOBI3	12.8	90	11.55	BORB10	1.5	70	1.03
BOBI4	8.3	85	7.08	BORB11	5.0	30	1.51
BOCC1	7.5	35	2.62	BORB12	11.9	80	9.49
BOCC2	6.1	75	4.59	BORB2	0.5	70	0.33
BOCC3	10.1	70	7.06	BORB3	7.5	70	5.22
BOCC4	10.4	40	4.15	BORB4	10.9	70	7.61
BOCC5	0.7	40	0.26	BORB5	0.4	75	0.28
BOCC6	56.4	85	47.92	BORB6	5.3	75	3.98
BOHC1	14.3	45	6.41	BORB7	4.7	30	1.42
BOHN4	3.9	90	3.49	BORB8	3.8	20	0.76
BOLB1	22.1	70	15.45	BORB9	7.1	80	5.66
BOLB2	0.4	30	0.11	BOSC1	15.6	80	12.50
BOMH21	4.0	85	3.39	BOSH1	0.2	10	0.02

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
BOSH2	0.4	20	0.08	DADP3	0.3	75	0.20
BOSH3	0.7	30	0.22	DADP4	0.6	75	0.42
BOSH4	0.5	50	0.26	DADP5	2.1	75	1.61
BOSH5	0.1	50	0.07	DALR1	2.6	50	1.29
BOTI1	3.4	20	0.69	DALR2	4.0	60	2.39
BOTI10	4.6	20	0.91	DAMP1	2.5	95	2.39
BOTI11	4.6	85	3.91	DAMP2	8.5	80	6.83
BOTI2	4.1	40	1.65	DAMP3	0.2	80	0.17
BOTI3	9.7	40	3.87	DAMP4	0.4	75	0.30
BOTI4	4.2	70	2.92	DAMP5	5.0	55	2.76
BOTI5	0.8	30	0.24	DANO1	9.4	70	6.56
BOTI6	1.3	75	0.94	DANO2	0.1	75	0.04
BOTI7	2.6	50	1.29	DANO3	0.1	70	0.05
BOTI8	5.6	85	4.77	DANO4	0.7	70	0.51
BOTI9	1.2	15	0.19	DANO5	0.5	70	0.37
BOTP1	8.8	65	5.72	DANO6	1.1	80	0.91
BOTP2	4.1	65	2.67	DANO7	0.4	70	0.30
BOWN1	18.6	60	11.14	DANO8	0.7	70	0.50
BOWN10	5.4	20	1.07	DANO9	0.2	70	0.13
BOWN2	13.2	65	8.55	DAOA1	4.6	70	3.24
BOWN3	3.9	65	2.56	DAOA2	5.3	80	4.25
BOWN4	4.6	65	3.01	DAOA3	5.6	30	1.68
BOWN5	0.9	40	0.37	DAPP1	1.7	80	1.35
BOWN6	1.7	40	0.69	DAPP2	1.6	80	1.30
BOWN7	0.3	40	0.12	DAPP3	0.9	85	0.76
BOWN8	1.5	35	0.54	DARH1	15.1	50	7.57
BOWN9	0.3	35	0.12	DARH10	0.8	65	0.52
				DARH11	0.2	65	0.15
Dartmouth beds				DARH12	1.5	65	0.98
DABJ1	1.6	80	1.30	DARH2	0.2	65	0.14
DABJ2	2.3	80	1.84	DARH3	1.9	65	1.24
DABJ3	10.4	90	9.33	DARH4	0.3	65	0.20
DADP1	1.4	75	1.05	DARH5	0.1	65	0.03
DADP2	1.3	75	1.01	DARH6	0.1	65	0.03

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
DARH7	0.1	65	0.06	FAGU2	5.7	75	4.30
DARH8	1.7	65	1.13	FAGU3	11.2	70	7.87
DARH9	0.4	65	0.25	FAGU4	4.4	95	4.18
DASP1	5.9	85	5.02	FAGU5	3.0	60	1.79
DASPP1	0.8	75	0.55	FAGU6	1.5	60	0.93
DASPP2	0.2	80	0.15	FAGU7	0.2	69	0.14
DASPP3	0.5	75	0.37	FAHB1	0.1	60	0.04
DASPP4	0.4	75	0.27	FAHP1	15.8	80	12.66
				FAHP2	9.1	25	2.27
Falmouth Beds				FALH1	2.8	60	1.69
FAGH1	4.8	100	4.85	FALH2	1.9	60	1.17
FAGH10	5.8	50	2.91	FALH3	1.9	75	1.40
FAGH11	0.5	50	0.26	FALH4	0.9	50	0.44
FAGH12	0.9	50	0.45	FALH5	5.0	50	2.52
FAGH13	0.9	60	0.56	FALH6	0.6	35	0.22
FAGH2	0.5	70	0.33	FALS1	1.2	75	0.89
FAGH3	3.4	70	2.41	FALS2D	4.8	50	2.40
FAGH4	0.4	55	0.23	FALS2S	26.4	95	25.12
FAGH5	3.2	75	2.37	FALS3	0.3	69	0.21
FAGH6	1.6	90	1.43	FAMH1	6.7	50	3.34
FAGH7	0.8	75	0.57	FAMH10	5.8	80	4.61
FAGH8	3.6	50	1.78	FAMH11	5.4	70	3.79
FAGH9	0.9	70	0.63	FAMH12	1.2	65	0.81
FAGS1	30.0	75	22.48	FAMH13	4.7	65	3.04
FAGS10	0.2	70	0.11	FAMH14	0.3	75	0.23
FAGS2	0.7	60	0.43	FAMH15	2.1	70	1.46
FAGS3	1.1	60	0.65	FAMH16	0.9	70	0.63
FAGS4	0.2	70	0.17	FAMH17	3.6	50	1.80
FAGS5	1.0	70	0.73	FAMH18	0.1	80	0.10
FAGS6	0.1	70	0.05	FAMH19	5.3	80	4.23
FAGS7	0.3	70	0.24	FAMH2	3.6	70	2.53
FAGS8	0.1	70	0.05	FAMH20	32.0	75	23.98
FAGS9	0.8	70	0.58	FAMH24	0.2	20	0.03
FAGU1	1.2	75	0.93	FAMH25	1.4	40	0.54

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
FAMH26	25.8	80	20.65	FAPP2	12.8	70	8.96
FAMH3	0.5	70	0.33	FAPP3	13.0	70	9.08
FAMH4	0.3	60	0.19	FAPP4	6.5	85	5.53
FAMH5	7.9	60	4.77	FAPP7	5.1	70	3.58
FAMH6	4.7	20	0.94	FAPP8	1.0	80	0.77
FAMH7	2.4	40	0.95	FAQH1	3.0	75	2.24
FAMH8	4.0	60	2.40	FAQH2	0.5	70	0.35
FAMH9	2.0	15	0.29	FAQH3	2.8	75	2.11
FANP1	3.3	75	2.50	FAQH4	2.4	50	1.20
FANP2D	2.4	80	1.88	FASD1	21.8	80	17.45
FANP2S	1.0	50	0.51	FASD2	26.8	85	22.75
FANP3D	1.0	60	0.60	FAWEP1	0.2	50	0.09
FANP3S	3.2	95	3.02	FAWFH1	1.6	90	1.41
FANP4	1.4	85	1.23	FAWFH2	6.3	100	6.31
FANP5	2.8	85	2.36	FAWFH3	14.0	75	10.51
FANP6	19.1	85	16.21	FAWFH4	5.4	60	3.23
FAOQ1	9.3	70	6.52	FAWFH5	4.4	60	2.65
FAOQ2	7.2	50	3.61	FAWFH6	5.3	50	2.67
FAOQ3	3.4	65	2.18	FAWFH7	1.9	50	0.97
FAOQ4	7.3	75	5.46	FAWFH8	1.3	50	0.64
FAOWF1	1.0	75	0.74	FAWH1	7.2	60	4.32
FAOWF10	0.8	60	0.50	FAWH2	0.2	50	0.11
FAOWF11	0.2	50	0.12	FAWH3	0.2	50	0.11
FAOWF12	0.2	50	0.08	FAWH4	0.1	50	0.05
FAOWF13	0.1	50	0.05	FAWH5	0.7	35	0.24
FAOWF2	3.9	60	2.36	FAWH6	6.2	50	3.11
FAOWF3	18.4	75	13.78	FAWH7	3.3	85	2.82
FAOWF4	1.4	90	1.26	FAWH8	0.3	30	0.09
FAOWF5	8.6	30	2.57				
FAOWF6	0.3	50	0.13	Fairhaven Beds			
FAOWF7	4.1	90	3.67	FRNB1	128.7	75	96.56
FAOWF8	9.3	50	4.66	FRNB2	49.4	85	41.96
FAOWF9	1.1	75	0.80	FRNB3	16.4	65	10.64
FAPP1	13.4	70	9.39	FRNB4	0.4	65	0.23

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
FRNB5	2.4	45	1.07	MRPI7	2.5	20	0.51
FRSN1	28.1	75	21.09	MRPI8	0.5	50	0.23
FRSN2	0.4	75	0.27	MRSH1	14.8	55	8.13
FRSN3	62.7	80	50.13	MRSH10	2.7	45	1.21
FRSN4	6.2	40	2.47	MRSH11	0.8	40	0.33
FRSN6	4.6	35	1.62	MRSH12	1.6	40	0.65
FRWI1	0.8	35	0.27	MRSH13	3.3	40	1.31
FRWI2	76.5	85	65.02	MRSH14	5.0	40	2.00
FRWI3	1.3	70	0.91	MRSH15	1.4	35	0.48
FRWI4	8.5	85	7.21	MRSH2	5.1	35	1.79
FRWI5	33.6	75	25.20	MRSH3	14.5	85	12.28
FRWI6	5.1	60	3.09	MRSH4	4.5	20	0.91
FRWI7	3.2	65	2.08	MRSH5	5.3	60	3.16
FRWI8	17.4	75	13.05	MRSH6	10.0	40	4.01
FRWI9	4.7	70	3.31	MRSH7	2.8	30	0.83
				MRSH8	1.9	30	0.58
Marion Beds				MRSH9	1.2	40	0.49
MRCP1	23.7	65	15.40	MRSN1	6.7	60	4.03
MRCP2	12.1	75	9.08	MRSN2	3.4	60	2.05
MRCP3	8.7	80	6.96	MRSN3	17.6	40	7.05
MRCP4	6.5	55	3.58	MRSN4	5.2	40	2.09
MRCP5	1.1	10	0.11	MRSN5	14.1	70	9.86
MRCP6	7.0	45	3.16	MRSN6	3.6	15	0.54
MRCP7	3.4	80	2.75	MRSN7	16.5	65	10.71
MRCP8	12.4	80	9.94	MRSN8	8.4	60	5.06
MRGH1	5.2	80	4.12	MRSN9	9.9	75	7.40
MRGH2	5.8	80	4.62	MRWC1	2.9	35	1.00
MRGH3	3.2	80	2.56	MRWC2	35.0	50	17.51
MRPI1	12.1	60	7.27	MRWC3	1.1	10	0.11
MRPI2	4.3	40	1.72	MRWC4	0.4	70	0.31
MRPI3	3.1	45	1.38	MRWC5	0.4	40	0.18
MRPI4	1.8	15	0.27	MRWW2	1.3	40	0.54
MRPI5	1.0	15	0.14	MRWW4	5.8	80	4.68
MRPI6	5.6	30	1.67	MRWW7	2.7	60	1.64

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
MRWW9	1.0	50	0.48	MTSP10	25.6	75	19.17
				MTSP11	3.1	60	1.88
Mattapoisett Beds				MTSP12	1.3	30	0.39
MTAC1	2.0	60	1.18	MTSP2	1.1	65	0.71
MTAC2	10.4	70	7.27	MTSP3	24.9	65	16.19
MTBI1	0.9	95	0.88	MTSP4	22.2	50	11.11
MTBI10	0.1	45	0.03	MTSP5	47.1	80	37.67
MTBI11	4.6	90	4.16	MTSP6	6.5	30	1.94
MTBI12	5.2	90	4.65	MTSP8	0.3	70	0.22
MTBI13	1.8	80	1.41	MTSP9	0.2	70	0.15
MTBI14	1.3	80	1.02				
MTBI15	0.2	80	0.13	New Bedford Beds			
MTBI16	6.2	80	4.98	NBFR1	0.6	25	0.16
MTBI17	56.7	95	53.88				
MTBI2	2.3	80	1.88	Wareham Beds			
MTBI4	5.2	90	4.64	WABB1	1.5	70	1.02
MTBI5	4.3	50	2.14	WABB2	5.9	85	5.05
MTBI6	5.4	80	4.33	WABB3	1.0	25	0.26
MTBI7	4.6	45	2.08	WABC1	8.1	30	2.44
MTBI8	4.1	90	3.65	WABC2	4.8	45	2.17
MTBI9	0.6	45	0.26	WABU1	3.7	69	2.58
MTHC1	9.1	80	7.31	WACN1	13.7	90	12.31
MTHC2	9.1	60	5.47	WACN2	1.7	80	1.39
MTHC3	13.5	75	10.10	WAGN1	107.0	75	80.27
MTMH1	26.7	60	16.01	WAGN10	4.0	50	1.99
MTMH2	0.5	10	0.05	WAGN11	0.2	75	0.15
MTMH3	0.4	85	0.37	WAGN12	1.5	85	1.27
MTMH4	14.1	60	8.44	WAGN13	0.7	80	0.53
MTMH5	20.4	60	12.24	WAGN14	44.9	75	33.68
MTMH6	25.3	70	17.71	WAGN15	7.4	85	6.33
MTNB6	32.4	80	25.92	WAGN16	138.0	55	75.89
MTRI1	33.5	60	20.10	WAGN17	64.4	40	25.78
MTRI2	7.1	30	2.12	WAGN18	38.9	40	15.57
MTSP1	5.7	60	3.40	WAGN19	1.1	70	0.80

Bed name	habitat area	% cover	bed area
WAGN2	0.7	80	0.59
WAGN3	91.1	40	36.43
WAGN4	33.2	30	9.97
WAGN5	1.2	40	0.46
WAGN6	1.1	50	0.57
WAGN7	0.3	85	0.25
WAGN8	1.3	75	0.96
WAGN9	0.5	45	0.24
WAHN1	4.5	80	3.63
WAHN2	4.9	90	4.44
WAHN3	5.2	90	4.66
WALB1	30.8	80	24.67
WAOB1	1.8	95	1.75
WAOB10	0.8	50	0.42
WAOB2	3.1	95	2.95
WAOB3	4.5	95	4.25
WAOB4	7.6	45	3.44
WAOB5	2.0	60	1.20
WAOB6	6.2	40	2.48
WAOB7	11.8	40	4.71
WAOB8	17.8	75	13.33
WAOB9	9.8	25	2.44
WAPI2	15.2	50	7.58
WAPI3	22.4	80	17.93
WAPI4	1.7	45	0.78
WAPI7	19.8	85	16.87
WAPI8	1.0	90	0.94
WASP1	1.8	65	1.17
WASP3	5.3	60	3.18
WASP4	16.5	80	13.20
WASP5	2.5	85	2.11
WASP6	6.0	65	3.88
WASP7	7.6	80	6.08
WASP8	6.3	70	4.40
WASP9	10.7	60	6.43
WASQ1	6.1	70	4.27
WASQ2	0.9	80	0.73
WAWC1	15.1	90	13.62
WAWC2	1.4	70	0.96
WAWC3	2.5	80	2.01
WAWC4	1.0	90	0.90
WAWC5	10.0	80	8.03
WAWR1	4.4	60	2.63
WAWR10	1.2	60	0.71
WAWR11	7.3	80	5.87
WAWR12	13.5	80	10.81
WAWR2	19.4	95	18.48
WAWR3	2.5	75	1.90
WAWR4	0.4	35	0.16
WAWR5	2.0	40	0.82
WAWR6	7.6	70	5.30
WAWR7	5.6	40	2.24
WAWR8	3.7	50	1.87
WAWR9	1.9	50	0.96
WAWW1	0.6	70	0.39
WAWW3	0.6	75	0.47
WAWW5	1.0	80	0.78
WAWW6	0.6	80	0.49
WAWW8	2.7	80	2.16
Westport Beds			
WEWB1	19.6	35	13.53
WEWB10	3.8	60	2.60
WEWB2	1.4	45	0.94
WEWB3	64.5	35	44.51
WEWB4	13.1	60	9.01
WEWB5	8.7	95	6.01
WEWB6	15.0	60	10.35

Bed name	habitat area	% cover	bed area	Bed name	habitat area	% cover	bed area
WEWB7	15.9	60	10.95				
WEWB8	5.5	90	3.83				
WEWB9	31.5	75	21.71				

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